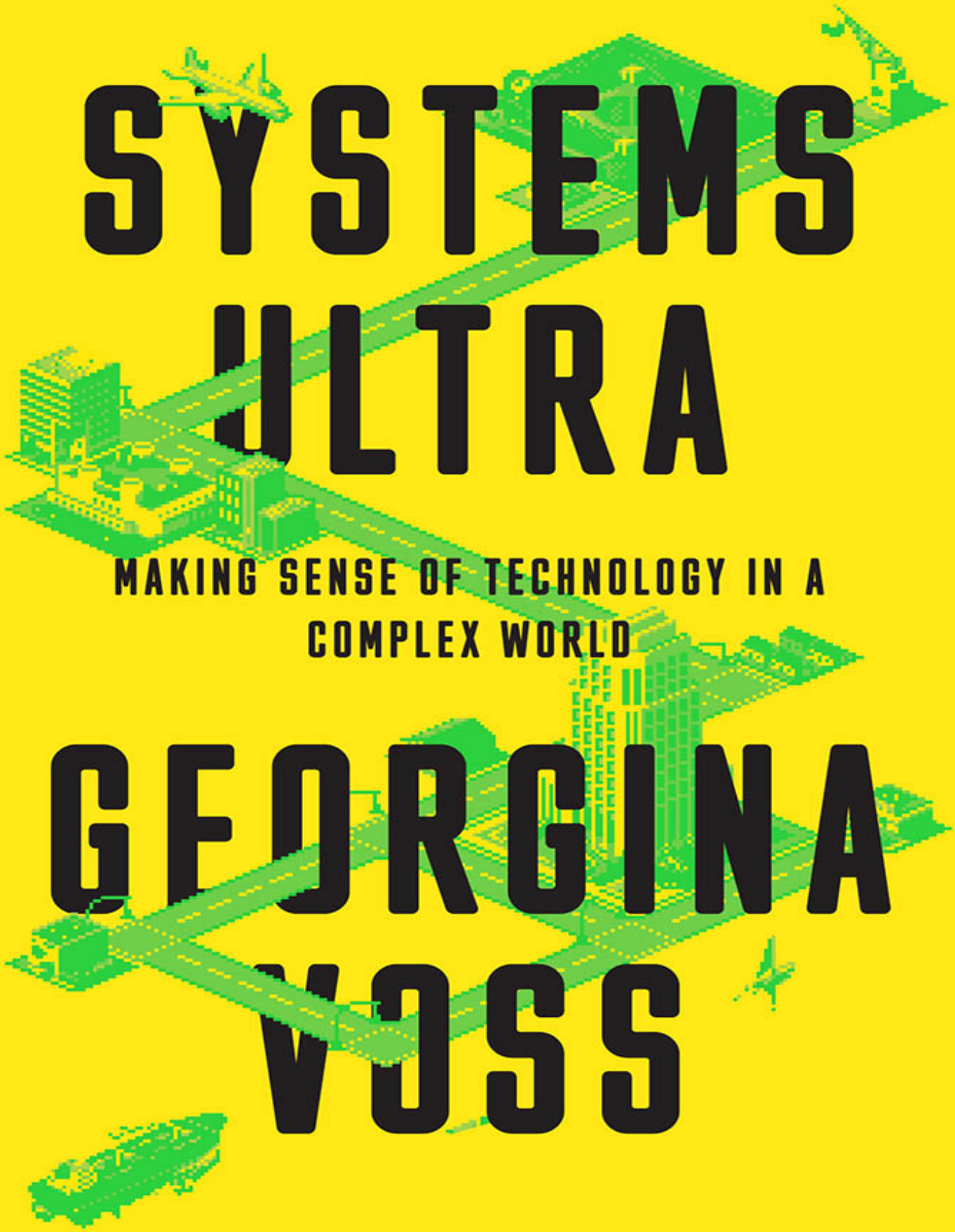
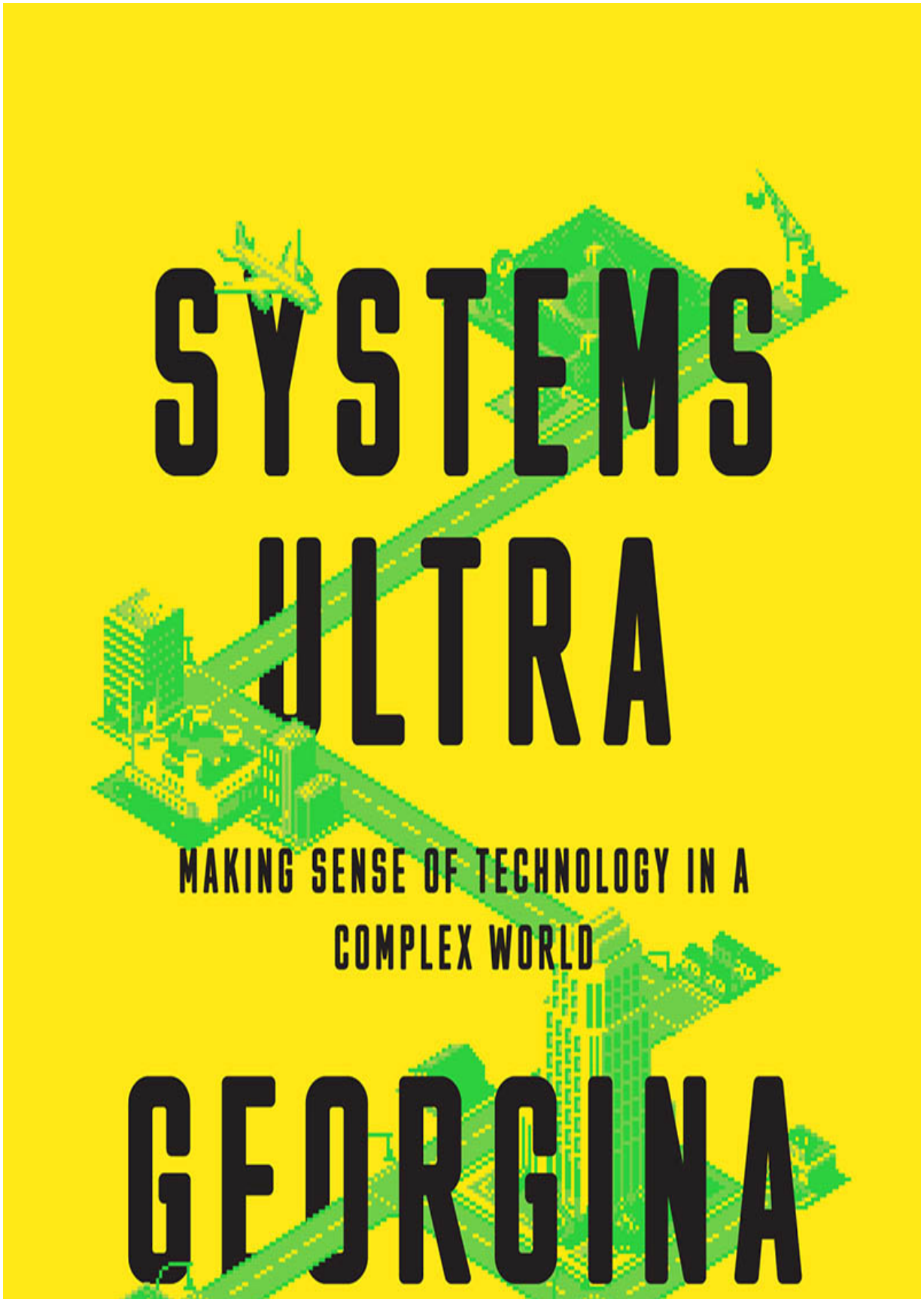
SYSTEMS ULTRA

MAKING SENSE OF TECHNOLOGY IN A COMPLEX WORLD



GEORGINA VOSS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Making Sense of Technology in a Complex World

Georgina Voss

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For Bruce and Taku

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Then you are back to metaphors and meanings.
My work has no meaning beyond the logic of its systems.
I have done away with emotion intuition inspiration spontaneity – aggrandised habits which set artists apart from ordinary people – those unclear tendencies which are inflicted upon viewers.

– Carole Schneemann, 1975

The Grid. A digital frontier. I tried to picture clusters of information as they moved through the computer. What did they look like? Ships? Motorcycles? Were the circuits like freeways? I kept dreaming of a world I thought I'd never see.

And then, one day – I got in.

– TRON: Legacy, 2010

1

Systems

The ceilings of the Las Vegas Convention Centre are higher than a cathedral. This week, these halls play host to the largest technology event on the planet. It is the heart of winter in the Nevada desert and CES – formerly known as the Consumer Electronics Show – has landed in the biggest building that the self-proclaimed entertainment capital of the world has to offer.

Visitors may have arrived via a monorail (a monorail!), sweeping above the city's battered freeways and swooping around glassy hotels, experiencing a pre-emptive touch of The Future before being delivered to the doors of the Centre. Frosted sunlight streams through glass walls into a colossally bright atrium. If you're here for the first time, maybe you feel a ripple, a trill of excitement as you traverse up and down the array of escalators and gentle carpeted slopes, and wonder: what delights and wonders of the new technological world await within?

Buckle up, because what's inside is underwhelming and confusing. This is not your beautiful future. The halls are demarcated into what are meant to be distinct zones but have such a similar feel that the overall effect is one of a fungal colony of car dealerships or sprouting nests of airport duty-free booths, where little nodes of brightly coloured widgets have budded, perched on little plinths. Repeat visitors know to bring comfy shoes to cushion their feet as they hike through miles and miles of a terrain of hype in search of the next big thing. But through the forest of stands it is very hard to ascertain what, or where, that might be.

Some of the limits of wonder are financially induced. It's hard to fill an enormous space without a sack of cash, and every exhibitor here has paid through the nose to attend. Proper theatre is only truly available to the very

richest. Only global tech giants can afford to buy the space to set up their stunts. Sometimes the space is nowhere near Nevada: in 2014, the GPU company Nvidia created a crop circle in the shape of a computer chip in a Californian barley field, as a promotion for its new processor.

Many of the rest of the folks here are what the writer Gian Volpicelli describes as the desperados in the small potato booths, shivering in air-conditioned plastic grids.[1] Money doesn't seem to buy imagination here though. Sure, it's a challenge to make a spectacle to market something as tiny as a microchip, or as immaterial as a new software platform, but everyone seems to be scared into using the same colour palettes and shapes. The curves are all the same. The lighting flattens everything into the same form. A visitor at the 2022 show is bathed in a vapourwave sea of soft light in pinks, greens, and purples regardless of whether they're inspecting Singaporean gaming hardware, or a tunnel built by the world's richest man. Something like the Google Assistant slide at the 2020 show – where attendees, clutching backpacks full of corporate swag, slide from on high into a ball pool – makes for good photos but is utterly untethered to what the technology itself does.

As you yomp through the halls, you will pass hundreds – even thousands – of stalls where eager vendors in branded polo shirts are ready to make the sell on their *thing*: a car, a phone, a tractor; a screen, some software, a shoe; a digital cockpit, a dog collar, a door handle. Deep down, you know that these are distinct entities. And yet: in the cavernous halls, your heart and brain both jacked up by tankards of coffee and deprived of natural light, every *thing* here is collapsed into a samey, inchoate mass.

There are no existential questions around the identity of the trifecta of trade shows that come to Las Vegas later in January. One week after CES has packed up and left town, concrete, guns, and pornography come to take its place and each industry is extremely secure and confident in who they are. Agricultural machinery takes over the Convention Centre as the building is repurposed for World of Concrete. Here concrete pumps nuzzle their noses against the ceiling, their Jurassic scale more suited to the size of the place. No questions here for the construction industry about its selfhood, as it fills the hall with gigantic machines and scaffolding and the parking lots outside with wall-building competitions and vehicle rallies, where drivers in road diggers careen around an obstacle course as fast as they can.

Across the road – the monorail will take you there! – is the SHOT show, a fully-functional acronym for Shooting, Hunting, and Outdoor Trade vendors who are also pretty comfortable with what they offer. No big surprises here among a swell of camo-aesthetics: here's guns, there's ammo, here's the FBI proffering leaflets on economic espionage, there's crystal manufacturers Swarovski, who make both glittering earrings and rifle scopes.

Further south is the Adult Entertainment Expo – AEE – where, in one hall, performers take selfies with fans, and in another, vendors sell 'adult novelties' (viz: sex toys). By necessity the sex industry has always been self-aware of who they are and how they are perceived. The only attempts to disguise themselves come through 'discreet' offerings such as the elegant pastel-green vibrator shaped like a stingray, though this is on show next to a vibrator that looks like a larger, angrier version of the body part it's modelled on.

In theory, CES could comfortably envelop guns, concrete and porn. Electronics and code have been seeping into everything for over fifty years, with networked connectivity now attaching everything to everything else. CES has indeed spread; what used to be a 'tractor' is now a 'cyber-physical entity' that farmers can lease but never truly own. At AEE, dozens of cam performers are livestreaming from the corridor where adult film actors used to do signings, indicative of how new payment infrastructures, streaming platforms and ring lights have radically restructured the industry to permit performers to engage directly with customers. The paranoia of the gun show has been augmented by software threaded into 'smart' security cameras and 'smart' locks which allow remote access to firearms.

It is easier to create a narrative for a thing than around the strange interconnection of things. Historically, these theatrics were what CES excelled at. In its earlier years during the 1960s and 1970s, the show was a more elegant and coherent affair. New-fangled devices with solid state electronics and imports from Japanese manufacturers were given a glamour and placed atop brightly coloured plinths coated in psychedelic swirls. Wristwatch radios! Portable phones weighing nineteen pounds and requiring an FCC licence to operate! Audio equipment was dramatically lit by spotlights against a brick wall, as if about to deliver incisive political stand-up.

The set design of the show created a legible whole. CES of 1972 has the blocky feel of a Playmobil kingdom where bright chunky stands are laid out on a primary-coloured grid system, scattered throughout with enormous lo-res monuments paying tribute to some electronic monarch. As electronics seeped into everything and software ate the world, the boundaries softened and blurred. Helicopters were on show at CES in 2018: asked by Volpicelli whether these vessels could be considered ‘consumer electronics’, a vice-president of Bell Helicopters replied breezily, ‘Sure.’

So perhaps it’s not surprising that CES is a hot mess of a Friday casual hellscape; a city superimposed on a city. It’s all a long way from the original expositions and world’s fairs of the nineteenth and early twentieth centuries that aimed to offer a coherent vision of a better future which was thematically tied to whatever the show’s theme was, even if that theme was celebrating the construction of the Panama Canal. The only canal around here is the artificial one in the Venetian hotel, where crypto bros set up shop under the unreal sunset to flog imaginary currencies. Across town, someone else has connected a bathroom mirror to a server. At the 2022 show, there’s a ‘futuristic’ truck on offer from the US Postal Service, whose main innovation is a larger cargo capacity to deal with all the parcels people are ordering from Amazon. I liked the USPS future truck much more than the Laocoön monstrosity of a car, also on show, that purports to transform from a vehicle into a gaming hub.

Maybe this is inevitable. How could anyone create an understandable story which ties together, say, the fabric of a device; and its tiny embedded sensors that track heart rate and location; and, embedded software that crunches this data to determine habit and behaviour; and the server farms that collect and collate this material through environmentally-intensive processes; and any ethical and political considerations around any single part of this process, let alone how all of these moving parts all interact with each other? (This is for a smart dog collar, by the way.) Background and foreground collapse into each other.

In the light of increasingly complex networked technologies and phenomena such as climate change, there’s been a growing rumble of calls for a new kind of systems literacy: not to treat these strange entanglements of nodes and connectors as definable *things* but to create a fundamentally different way to know them. This goes beyond the airport-bookshop model of systems thinking which tends to involve a lot of graphs and urges to

‘shift your mindset’. Writing about the emergence of complex information systems, James Bridle makes a call for an urgent understanding of these systems and their ramifications.[2] Everyone agrees that a vocabulary for these assemblages is a challenge, though.

Systems, Donella Meadows writes, are structures defined by relations, with parts that stand together and relate to the whole; and thus are notoriously difficult to articulate in writing. They cannot be described in a neat, linear way, but through a language that shares some of their properties.[3] The philosopher Timothy Morton goes further, describing certain types of sprawling complex systems as ‘hyperobjects’, such as the internet and climate change, that exist through space and time. They are difficult to approach, hard to conceptualise, emerging and submerging through our limited human consciousness.[4]

There’s a very human hand at play on the show floor, though, which also shapes how the man-made systems on sale are not only built but known. As we have seen, CES should theoretically be able to easily engulf guns, sex, and construction into its maw, but these categories have minimal presence at the event. Military funding underpins the technological functioning of nearly everything on show, but there’s no specific category for firearms or defence products. ‘Vehicle Tech’ does have its own area, but a lot of what is on show is closer to vapourware than the fully functional machines which are ready to roll out of the concourse at World of Concrete and on to the construction site. At CES, a car is more often a concept intended to carry an idea, than a vehicle to carry actual passengers.

And then – oy! – sex. In 2019 an elegant vibrator made by Lora DiCarlo – visually indistinguishable from many of the other, tamer, rubbery, white, curved devices on show – won the ‘honoree’ designation in the ‘Robotics and Drones’ category at the CES Innovation Awards. Although ‘sex tech’ has been at CES for a while, the Consumer Technology Association, which runs the award, freaked the hell out and revoked the prize. After a flurry of complaints, the award was reinstated, and sexual health devices were allowed to compete for the prize the following year. The whole shebang exemplified how weird CES gets around sexuality and gender. Despite giving rise to the accursed form of booth babes, women (and men) who augmented the show’s atmosphere with ambient vibes of attraction and

seduction, CES is really quite uncomfortable with the actual erotic, banning products which it deems to be immoral, obscene, indecent, or profane.

Systems do not just happen. Those on show at CES may be constructed materially, but their comprehension is culturally reinforced. By the show's end, feet aching, caffeinated into the sun, trapped in the swell of several thousand lanyarded attendees, and staring at what describes itself as a 'Smart Door', you may ask: truly, what the hell is going on?

This is a book about making sense of what is meant by 'systems'. I will be honest: one of the biggest and dumbest challenges here is that it is extremely difficult to write about systems given that they cannot adequately be described using words. Think of a system and you might think of a headache of a diagram in a PowerPoint presentation, filled with cross-hatched lines and sprinkled with phrases such as 'Pig Model' and 'Rich Picture'. At their core, systems are about the relationships between things, and then the relationships between those relationships. Lots of attempts to comprehend systems rest on fomenting a technical understanding of how these parts interlock and affect each other; and thus the horrible diagrams. Verbal attempts to neatly encapsulate what a system is can feel like a stoner monologue with pointed hand gestures ('Have you ever thought about how electricity is, like, *really big*?').

But system also has a meaning of its own. As a word, *system* is often used interchangeably with *technology* and *infrastructure*. While different, the three share cultural expectations. They have a similar texture of technocratic authority. You might expect to see any combination of *technology*, *system*, and *infrastructure* on the cover of an airport management book, or in the slide deck for a RAND report. These terms imply some crucial power structure, bound to an expectation that to understand it is to control it. Those who can control it, do, and woe betide anyone who finds themselves on the wrong side of that power dynamic.

Systems are both structure and behaviour. These interlinked complexities of systems create the challenge of talking about them and the meanings that get loaded on to them, but not in a way that is immediately obvious. Donella Meadows takes a structural approach, exploring how the relationships set up in a system can behave, often in unexpected ways. Systems are surprising, she tells us.[5]

A diagram can be useful for showing *how* this surprise is created: a strangely shaped truck is designed because networked technologies and supply chain flow means that lots of people are ordering lots of parcels online. But another surprise is that trite refrains are actually pretty good for describing process. ‘A stitch in time saves nine’ is the easier articulation of, ‘Because of feedback delays within complex systems, by the time a problem becomes apparent it may be unnecessarily difficult to solve’.

In other words: systems can be more easily comprehended second-hand and indirectly; that is, as metaphor. The design scholar Dan Lockton argues that a system is a fiction created to understand invisible relations, in which metaphors are used to make abstractions tangible and shareable.[6] Systems are therefore both conceptual – a way of knowing the world – and something which is really there.[7] The metaphors that Donella Meadows deploys in *Thinking in Systems* to describe specific qualities of systems are pretty general. But metaphors are not neutral. They carry their own meaning which seeps into how their subject is seen.[8]

What do you think of when you think of a system? Maybe you do as the characters do in John le Carré’s novel *The Constant Gardener*, for whom the System is the British Empire: corrupt, violent and powerful, its tendrils stroking every corner of the globe. Perhaps you were out in Brighton last autumn, placing neon stickers on walls which read: ‘If we don’t want to un-fuck the system, baby, we’re fucked.’ Maybe you align with the art collective Black Obsidian Sound System who state: ‘The only good system is a sound system.’ Maybe you remember Morpheus telling a wide-eyed Neo, ‘The Matrix is a system, and that system is our enemy.’ Maybe you don’t even think of the word ‘system’ but go directly to TV shows where detectives and would-be detectives jab at a wall collaged with mugshots and scraps of paper and pinned with red string, trying to make sense out of the mess. Fiction and creative work is so good for viscerally demonstrating the frustration and anger that comes with existing within a large and powerful structure whose behaviour is set against you.

But maybe when you think of a system, you think of a car that links combustion engines to sensors to wheels to driving. Maybe you think of hundreds of thousands of large ships, stacked high with steel boxes, sailing day and night across the oceans to bring you those cars. Maybe you think of millions of lines of code which track the movement of those ships and their

boxes and everything which is inside them. Maybe you think of the strange things that happen when any part of this gets disrupted; say, in a global pandemic.

People fall ill; workplaces close; factories reduce production of semiconductors; manufacture of devices dependent on those semiconductors, like cars, also slows. Cities shut down; borders close. Any stock lucky enough to leave the factory and find its way on to a container ship might now find itself waiting for weeks and months offshore. Not enough stevedores to remove them from the vessels. Not enough drivers to transport them elsewhere.

None of this was a surprise to anyone who spent time working to the drumbeat of 'if this then that' which defines operational logistics, but the COVID-19 pandemic shined a light on the structures that kept the world in flow and the visceral frustrations which came when they snarled up. 'IT'S A GREAT TIME TO BE WRITING A BOOK ABOUT SYSTEMS,' I messaged a group chat in the heart of one of the winter lockdowns.

How systems are imagined has enormous consequences.[9] It's common to find fictions and metaphors clustered tightly around new technologies early on in their inception to steer their development. Human-made things do not cleanly emerge into the world at the end of a tidy process but are tugged and tossed around by social and political forces that shape what these things are and will be. In the early stages of development when what a *thing* is is as messy and fluid as batter, fictions and metaphors act as the tin to pour the batter into and shape it as it bakes.

Take the idea of autonomous vehicles, which has been hyped at CES for years now. None of them exist in any complete, mass-manufactured way. You cannot contact a dealership to buy one, nor take any of the models from the show floor out into the streets. What's on display is partial and experimental: combinations of engines and sensors, beacons embedded into highway asphalt, and student projects. Any so-called self-driving cars out on the roads exist under test conditions. But none of this uncertainty is on show at the show.

Instead, the idea of the autonomous vehicle is sold with absolute self-confidence. People are now passengers, which is all for the best given that, as one autonomous tech multi-billionaire, put it, 'You can't have a person driving a two-ton death machine . . . It's too dangerous.'[10] Rather than

bringing their fallible human error behind the steering wheel, humans can use their time reading enormous business reports, having work meetings, or chatting to their families on huge screens; this at least is how the glossy marketing images at CES sell it. Roads become safe and traffic is more efficient, goes the story; pollution levels drop, cities become liveable.

Most of all, this picture is painted as assured, the inevitable tug of technological progress. Despite the fact that manufacturers say that building self-driving cars is much harder than they anticipated, and that lethal accidents show that the vehicles are far less intelligent than their reputations would suppose, what's on display at CES is 'The Future of Mobility'. Not *a* future, one of many, but *the*, a singular destination. The aim of this grand theatre of hype is not to structurally explain what this system of technologies does, but to persuade the audience of the truth of the story in which these technologies live.

Social scientists describe this process as a sociology of expectations.[11] New technologies can only exist through how they are expected to behave, and the visions that shape their potential. The stories around autonomous cars and cryptocurrencies and smart dog collars are not just pitched to customers, but are part of a bigger sell to politicians, journalists, moneymen. With a convincing story and appealing metaphors, one will be able to gather investment and guide R&D until what was not, now is.

Language implicates reality: the ideas we attach to things become things in the world. We use metaphors to describe things that elude our grasp, and fictions and metaphors allow an imaginary concept to be legitimated. These metaphors and stories are produced in a crucible of time, place, and culture. These narratives are hugely influential in the design, regulation, and reception of large-scale technologies and infrastructures. They shape how we expect the world to work. It is therefore possible to trace a line between the Californian Ideology of progressive utopianism and techno-libertarianism, and the story of the autonomous car as something built for the public good, while also making mass transit obsolete.[12]

To get to grips with what systems are and how they've been sold to us, we need to start at the beginning. So: where did the idea of systems in Western thought come from?

'System' is a ubiquitous concept – throw a stone and you'll find the idea of an omnipresent form in which things are purposefully joined together in

a certain way. As the technology anthropologist Valerie Olson explains, ‘system’ can describe an idealised interconnected coherent structure, but so too can hierarchies, rhythms, and assemblages.[13] What I want to do here, guided by Olson’s work on how ‘system’ is strategically deployed as an authoritative scientific and philosophical metaphor, is to trace where this metaphor comes from, and why it has such influence on technology and politics – not to reify it, but to dismantle it.

For brevity, I’m going to focus on two crucial points in this history: the emergence and propagation of the concept of ‘system’ in early modern Europe, and its resurfacing in mid-twentieth-century North America in cybernetics, Cold War strategies and, ultimately, Silicon Valley.

Let us start on a cold night in Italy in 1610, where the astronomer and engineer Galileo Galilei is peering through a spyglass at the winter night sky to see the planet Jupiter. On either side of the planet, Galileo saw a dotted line made up of several points of light, very small but very bright. ‘I therefore conclude and decided unhesitatingly’, he wrote, ‘that there were three stars in the heavens moving around Jupiter, like Venus and Mercury around the sun.’ That is: those little points of light were moons.

Why did this matter? Galileo was not the only person out stargazing with a fancy telescope (‘a very excellent instrument’, he notes approvingly). Finding a gaggle of new heavenly objects was not that big a deal. What was important was the relationship between these objects which Galileo understood to be comparable to that between Earth and its own moon. The Jovian satellites revealed that Earth wasn’t the only centre of rotation in the universe, and *that* implied the possibility of other similar set-ups. Finding a system in the natural world is like finding a mouse in the kitchen: it implies the presence of many more like it.

Galileo’s revelation was what the historian Clifford Siskin calls load-bearing knowledge: both an idea that could be used for thinking specifically about Earth and Jupiter, and an analytical tool in its own right. It provided the empirical proof to Nicolaus Copernicus’s hypotheses of heliocentricism. Galileo wrote all of this up in *Sidereus Nuncius* (‘Starry Messenger’), a short tract peppered with observations and sketches. The illustrations were important in conveying what words could not, emphasising that human senses alone weren’t sufficient to grasp the entirety of the natural world, and perhaps not even to be trusted. There were drawings of the surface of the moon which showed it to be cratered and scarred, not the perfect

smooth surface which had previously been imagined. And, of course, a sketch of that line of three stars with a circle nestled between the second and third.

In Enlightenment Europe, the notion of system circulated first as a scientific framework. Isaac Newton gave further credibility to the concept when he treated gravitational forces as a system; both as mathematical calculation to describe specific incidences, and as a common force aligning the stars in their heavens.[14] Through *Sidereus Nuncius* and Newton's *Principia Mathematica*, the concept of system was propagated through print media, allowing it to circulate and be reproduced and appropriated. It travelled, out of mathematics and astronomy, where it was associated with natural phenomena, and into philosophy, where it became abstracted. Here 'system' was transformed into a wholly conceptual framework that any discipline could drop its ideas into.

The anthropology scholar Marilyn Strathern describes how this transformation was made possible by another structure which had emerged during this period out of English kinship law. The 'relation' was a legal 'logic of totality' which allowed principles and forces to exist beyond the sum of their parts.[15] This logic allowed the elites of the Enlightenment to strip a structural framework from its context, appropriating the scientific principles of post-Copernican cosmology into a philosophical tool which could be used to analyse *any* structure defined by relationships – but, crucially, without disturbing the existing logics of Western patriarchal thought and racial order.

When used by philosophers including Immanuel Kant, René Descartes, John Locke, Georg Wilhelm Friedrich Hegel, and Alexander von Humbolt, 'systematicity' became not only a structure for thought but – as Valerie Olson describes it – a *sensibility.* To work with systemic frameworks, therefore, was a hallmark of good thought, demonstrating completeness and order. It also allowed its proponents to sweep aside any annoying real-world contradictions that might stick their heads up.

'System' became a totalising and simplifying concept. If something from the real world did not fit into its binding principles, it could quietly be glossed over. To demarcate something as a system tied mathematical fact to philosophical truth – and, under a systemic framework, the way that knowledge was produced also represented what reality was.[16]

To recap, then: by the nineteenth century, the idea of ‘system’ had emerged as a powerful scientific and philosophical metaphor. It had moved from astronomy and physics into philosophy and the wider natural sciences, carrying with it the authoritative stain of scientific enquiry, but with no self-awareness of the underlying logics that allowed it to extract this authority from its original context. The totalising nature of ‘system’ did attract criticism from some quarters, with scholars unpacking some of the mechanical orderliness to consider how structures such as slavery and economies sat against the concept.[17] But none of this did anything to dismantle the dominant mode of ‘system’ and if anything, only scaffolded its prominence by offering further ways to think about it.

This leads on to the second stage of system history. By the early twentieth century, a system was understood to be closed, controllable; a politically inert thing.[18] Its mechanistic nature had served it well in the physical sciences. Now, in the 1930s, it found a new playground in the comparatively new field of the biological sciences, where scientists began to explore how the idea of systems could help them understand the relationships between the parts of living things.

In Austria, the biologist Ludwig von Bertalanffy applied mathematical modelling to biological entities to create models which described how an organism grew over time. From this work, he built out a ‘general systems’ model which spliced biological and environmental elements with a semi-automatic mode of behaviour. Like its Enlightenment forerunner, a system was still a group of interacting parts that, together, made a whole.

In framing a biological entity as a system, von Bertalanffy radically reconceptualised what a system could be. The previous closed-system model based on thermodynamics didn’t function when applied to the many complex classes of living organisms. For biology, an open approach was more suitable whereby something – matter, energy, information – could transfer through a system in any direction. But more importantly – especially given the all-and-anything flavour of CES, many decades later – by expanding the systems concept into biology, the idea of a system was now applicable to anything in the known universe. Star clusters, socio-economic structures; plants, people, and machines; all systems, if you wanted them to be.

Von Bertalanffy's 'general systems' model was enormously influential, travelling back over again to engineering and mathematics, shaping the development of the fields that we now know as informatics, systems engineering, social systems theory – and cybernetics. It is the latter that gives us the clearest through line to the chaotic rat king of WTF systems understanding (or lack thereof) that I talked about earlier.

If you'd been hanging around Cambridge, Massachusetts in the late 1940s, in the long hallways of the Massachusetts Institute of Technology, you would have seen the new discipline of cybernetics take form. Established by the MIT mathematician Norbert Wiener and building on his wartime research on anti-aircraft systems, cybernetics argued that biological forms and mechanical forms could be understood to operate in the same way: as closed systems controlled by internal feedback loops. This meant that, as von Bertalanffy intimated, biological forms such as human beings could both be understood as systemic forms *and* be enmeshed into larger systems with human-made machinic elements. A pilot in a fighter jet could thus be understood as one system – a human – integrated into another system – a machine – which, together, formed a new, complex assemblage greater than the sum of its parts.

The subtitle of Wiener's book *Cybernetics* was *Control and Communication in the Animal and Machine*, which gives us a pretty good idea of the power relations in these systems. In Newtonian systems, gravitational forces provided feedback. In a cybernetic system, feedback was created by information that was generated and flowed between the nodes of humans and machines, each considered equal and interchangeable within the cybernetic ethos.

Cyberneticists pulled a similar trick to how enlightenment philosophy had stripped 'system' of its context to turn it into an authoritative tool. Biologists working with systems theory had been clear that living forms were functionally and materially distinct to mechanical and inorganic structures and had their own set of behaviours. In cybernetics, these differences were flattened out and redefined into technical terms of feedback, control, information, homeostasis: anything could be passed through the cybernetic hoop and find itself known.

Although cybernetics defined itself as an interdisciplinary field from the start – less science than metascience – it was still grounded in an authoritative, technocratic way of approaching the world. It was sold to

government bodies as a ‘universal language’, battening together biological principles, autonomous machines, and computational languages to form an enthralling proposition for defence departments wanting a more effective war machine.

For more than two decades, the US military amply funded cybernetic research. But when moved into actual applied practice, cybernetics became trapped in a gravity well of its own making. Grounded in technical theories of information and mathematics, it demanded that the subject under investigation be understood and operate on those terms. When faced with the truculent realities of flesh and culture, cybernetics collapsed like a flan in a cupboard.[19] Plenty of research was conducted into the intersection of humans and machines but nothing really stuck.

It’s a divide that continues in the CES shows today. The idea of the ‘cyborg’ – part human, part machine – abides and remains deeply influential on robotics and health-tech research. And yet, more than half a century later, there are no cyborgs at CES. On display is either a technological system which monitors and analyses a living being, such as our smart dog collar, or a technological system which emulates the aesthetic form of a living being, whether the terrifying Boston Dynamic robotic hounds or the cuter KODA pups that resemble Terminator dachshunds.

Rather than doing the heavy lifting around how intricate forms of biological life might physically intersect with inanimate machine, proponents of cybernetics leaned heavily on analogy. Its promise was so thrilling that the small stuff – the material composition of the world and the physical forces governing it – were nudged aside, in favour of grander visions. Wiener himself expressed doubt that cybernetics could be applied to disciplines such as economics or anthropology, which did not generate sufficient data to generate the predictive models necessary for cybernetic modelling.

As the first wave of cybernetics collapsed in the early 1960s, cybernetic enthusiasts were applying this so-called universal language to everything – from photosynthesis in plants to mass religion. Information theorists began drawing a protective boundary around their discipline to protect it from being shoehorned into any context. By its endgame, mired in hubris and its scientific credibility shot, the historian Ronald Kline describes how cybernetics had become a byword for cranks: a confidence trick which permitted people to rush into areas they had little understanding of, but

which they felt they could design and control.[20] The mathematicians and physicists who had been a part of the original community had now been replaced by a 'lunatic fringe', as the psychologist Michael J. Apter described them, with 'an inclination for the obscure and an aptitude for creating neologisms'.[21]

Let's briefly pause here and summarise. In the period between the 1930s and late 1960s in the United States and northern Europe, the concept of 'systems' was picked up by two nascent scientific fields. First, by biologists, who expanded the remit of 'system' to include living organisms; and then by mathematicians and physicists who adopted this updated concept, stripped it of its context, and packaged it up and put it to work as a compelling metaphor to sell defence research.

Uncoupled from biology and culture, and embedded in a military-academic landscape, cybernetics kept all of the earlier allegorical meanings of 'system' – totalising, universalised, patriarchal, abstracted – and added another set of associations – controllable, apolitical – to the pot.

It's worth noting here that cybernetics found enthusiasts away from the US who brought their own political allegiances into play. Perhaps most well-known is the British mathematician Stafford Beer, who worked with the Chilean politician Salvador Allende on Project Cybersyn, which explored what a systems approach would look like through a socialist lens. Could one design a centralised, computerised, 'command and control' structure which treated the economy as a delineated system, adjustable to increase productivity, while allowing agency and dignity to workers? With its control room's gentlemen's club aesthetics (including a pisco bar) and socialist principles, Project Cybersyn seemed to be light years from the militaristic intents of its US counterparts. Yet it embodied many similar elements: designable, predictable, controllable; untethered from human agency, and blind to its own inbuilt biases. Like some of the models on show at CES, many parts of Project Cybersyn's control room did not actually function but were finely crafted prototypes: what were meant to be visuals on computer monitors were in fact hand-painted screens.[22]

The field of cybernetics may have collapsed but, like 'system' several centuries earlier, the ideas and ideology floating out of it found fertile ground elsewhere. Cybernetics' weirder tendencies and cultish forms landed in 1960s psychedelia where, led by Stewart Brand, they formed the

stalwart of the counter-culture movement. Meanwhile, cybernetics' scientific authority, militarism, and conceptualisation of a 'closed world' that could be controlled from the top, found a home with the emerging Cold War technologies of control whose networked computational power cashed the cheque that cybernetics had written.

The historian Paul Edwards has described how each of these strands were able to pick a different metaphor out of the cybernetic ideology that sustained a belief system for them – and which together, crucially, underwrote the practical construction and metaphorical consideration of the world as a system subject to technological management.[23] Resonating and entangling, the strands operated under a shared ideology of what a system was which, over the following decades, underpinned a culture that birthed Silicon Valley, in Menlo Park and the Bay Area.

Through the dominance of the Californian Ideology and American, more-powerful-than-a-nation-state technology behemoths, the conceptualisation around what a technology is and how the world should behave has become rife, entrenched into industry, politics, and culture. Their implied neutrality makes these stories particularly pernicious, creating an implicit understanding that it is only natural that the world behaves this way. Supply chains might get glitchy, but the import of this ideological model around the world has been fast and frictionless.

These stories take flight at CES, infused by the absolute conviction that, with the right technological setup, anything can be solved. Maybe this is not really a surprise: CES is, after all, where technologies are sold. Silicon Valley isn't CES – its history is closer to small-c conservative infrastructure-scale, defence-funded contracts than the ball pool in Las Vegas implies, but it carries similar ways of thinking. This is not engineering expertise being carefully applied to solve urgent problems, but the imagining of a problem whose existence and solution is couched in the language of engineering expertise.

In her start-up memoir *Abolish Silicon Valley*, Wendy Liu recalls trying to find an application – any application – for her company's product. 'Our perspectives were immature and half-formed, with no theoretical basis, but we figured we could figure anything out from first principles,' she writes. 'We were smart, we had studied computer science, we had read *Zero to*

One, and *The Hard Thing About Hard Things*, and *Freakonomics*: we could boil down any problem to a neat object-relational mapping exercise.'[24]

As Liu comes to realise, her perspectives have been shaped by her education. As a coder, she is skilled, but her undergraduate degree in Mathematics and Computer Science, and self-taught online tutorials focused on instilling exceptional technical expertise – a universal language! – over a more holistic, interdisciplinary approach. She only acquires the language and tools to really understand and critique her experiences of modern start-up culture after a postgraduate degree in the social sciences.

Yet teachers have a hell of a task in pushing back on how young people conceive of 'technology' as mindset, not function, by the time they arrive into higher education. The artist and design professor Sara Hendren describes beautifully how, by the time they arrive at her studio, her undergraduate students already cleave to an idea of 'technology' which is tightly coupled to a saviour complex:

> My engineering students had come to class with technology on their minds. They were drawn to things like artificial limbs and corrective gear for sensory disabilities – hearing aids, for example, or sophisticated navigational canes. From our early discussions, it was evident that they'd imagined themselves making impressive technical tools that would perform a curative restoration, a gift exchange for the people we work with, and an encounter from which they'd learn a little something along the way.[25]

In my own teaching experiences, these attitudes around technology being universally curative are so common that my colleagues and I have, at times, had to ban students from developing an 'app' as the answer to any brief, regardless of context. What really makes my blood pressure rise are projects which begin, 'In the future we will . . .' At first glance, this type of introduction simply pushes back the arrival date of miracle technologies. It often resembles Wendy Liu's panicked brainstorming to 'solve' sandwich delivery using machine learning. But it is also an admission of failure. People aren't acting as we need them to in order to exist with this new technology. Cities haven't been built in the necessary way. Buildings aren't right either, and your pet could definitely be upgraded.

'In the future . . .' is rife at CES. It smooths the gap between the cracked asphalt on the roads outside the convention centre and the promise of new sensor-embedded freeways that autonomous cars can navigate. 'In the future . . .' offers a familiar world with the same old culture but now, we have jetpacks. Or apps. Or app-controlled jetpacks. 'In the future . . .' asks

you to look the other way. The uneasiness and '. . . the fuck?'-ness of walking the show floor is your gut's response to being asked to black-box and seal off these weird entanglements. It's a sticking plaster over what centuries of Western thought have wrestled down that structures defined by relationships behave in a certain way which might be replicable, but you're a fool to think that you can bind them perfectly to your will. There is a crack in everything.

So where do we go from here?

You cannot have an industry show without an awards ceremony. At CES, design and innovation are rewarded through the aforementioned Innovation Awards, even if they struggle to celebrate the erotic. Vibrators and the like are honoured without embarrassment at the pornography trade fair's 'O' awards, a friendly and intimate (genuinely no pun intended) event which is sufficiently attuned to the needs of sexual pleasure to reward innovation in both internal *and* external stimulation. There are vibrators too at World of Concrete, but of a different scale: machines which physically vibrate air bubbles out of curing concrete to create a flat surface. The need for flatness in the built environment is recognised through the Golden Trowel Awards, which rewards those with outstanding accomplishments in 'the art and science of high-quality horizontal concrete construction'.

Problem solving is a major irritant when coming to terms with how complex systems can be comprehended. In 1973 the Berkeley professors Horst Rittel and Melvin Webber took aim at 'systems thinking' which had, off the back of cybernetics and its ilk, crept into institutions like their own. In 'Dilemma in a General Theory of Planning', the pair criticised their peers in design and urbanism who felt blissfully confident that they could analyse social problems such as homelessness or poverty by using so-called systemic procedures for:

> continually searching out goals, identifying problems, forecasting uncontrollable contextual changes; inventing alternative strategies, tactics, and time-sequence actions; simulating alternative and plausible action sets and their consequences; evaluating forecasted outcomes; statistically monitoring those conditions of the publics and of systems which are judged to be germane; feeding back information to the simulation and decision channels so that errors can be corrected.[26]

The problem was not the techniques. Every method in that long list was perfectly valid in its own right, but only suited to certain types of problem-

solving. The areas where this approach simply did not work were what Rittel and Webber defined as ‘wicked problems’. These were the problems that resisted the one-size-fits-all approach of systems theorising. They manifested in unique ways and were extremely context dependent. A wicked problem could be ‘solved’ over and over again, but each outcome would bring myriad unintended consequences. Want to solve homelessness by building low-income housing? Great, but that might result in high unemployment clustered around the housing; and round we go again. Rittel and Webber bluntly stated: ‘The search for scientific bases for confronting problems of social policy is bound to fail.’

Wicked problems could have marked the end of the blanket application of the simple solutionism of systems thinking. If you’ve been paying attention, you can probably guess what happens next. Saturn devours his son. Half a century after ‘Dilemma . . .’ was published, wicked problems have become ‘Wicked Problems’; packaged up and repurposed as a subject of ‘design thinking’, and – that’s right! – stripped of its original context. Wicked problems are still problems, right? – and that implies that they have a solution. I truly believe that the exhortations of impossibility transformed them into a challenge which could, eventually, be solved by the smartest person in the room. Rittel and Webber’s observation that a systems perspective inflates analysts’ confidence to know the world remains intact.

Perhaps instead of trying to make any kind of sense of complex systems from outside, it’s worth grappling with what they feel like from the inside. This resonates with the philosopher Timothy Morton’s take that sprawling and complex forms of hyperobjects cannot easily be approached or conceptualised through cognitive analysis, but instead felt out as strange things that we grasp at, briefly, as they pass through our consciousness.

This way of approaching the world is resonant with the Romantics: developing knowledge through sensory experience, driven by passions and senses; a pushback from the same Enlightenment era which valued reasoning over emotion. Hyperobjects owe a lot to the sublime as elemental forces which can only ever be comprehended through absolute embodied experience – awe, say, or terror; something to be felt, not argued with.

There is something rather wonderful about simply *feeling* our way through these enormous structures. Imagine that instead of having to try to make sense of what or where the internet is, or why it is connected to this mirror – one could simply lean back and let the thing wash over you,

poking up here and there in street markings and cooling systems, which folds time as it starts with electron guns and ends with durational performance art. We don't have to worry about the political bent of these systems or how to engage with them any more than we would a storm at sea. They exist beyond the human scale and perception, far beyond our control.

Except that they don't. Galileo's systems may have been balls of fire and rock, hauled together by physical forces, but the systems that have come afterwards have been created by people, put to ideological ends with real-world consequence. Human-made systems such as supply chains, complex networked technologies, or global finance are relational structures, of course, but often only framed as neutered, impartial diagrams. The language around systems is neutral, describing structure and behaviour – but, as we've seen, there are powerful culturally-mediated meanings attached to what we expect of systems. Visceral, embodied interactions and paying attention to the weird ways in which systems puncture the world are incredibly important but need to be coupled with awareness of the power relations that course through them.

In her essay 'The Tyranny of Structurelessness', Jo Freeman describes how a community that won't acknowledge power cannot address it. Striving for a group without hierarchy is as deceptive as the idea of 'objective' news: perceived structure-lessness is a way of masking power, a smokescreen for the strong to establish control over others. Without addressing the power dynamics in their midst, communities are doomed to be governed by them.[27]

Throughout its history, the idea of systems has become expert at peeling apart the relations from the context, replicating and reinforcing the power structures that sustain it. This is why a systems literacy is particularly vital when challenging tradition and working towards dismantling social inequity. The institutions which deployed systems frameworks through militarised command-and-control assemblages and privatised financialised technology sectors are, I suspect, acutely aware of the dynamics and behaviour of these structures.[28]

On the flip side, however, even those who fight against social hierarchies can silo components of a system from each other, either misunderstanding or glossing over structural dynamics. These limits are

particularly acute around complex technology: writers and activists who are able to think lucidly around social injustice and labour movements suddenly lose their minds at the promise of some wonderful shiny thing. Calls for, say, a fully automated luxury communism paint a compelling view of how those wicked problems of poverty and social inequality can be ‘solved’ with some grab-bag of robotics, 3D printing, and comrade algorithms. The intentions are good but there’s little sense of how these curative technologies will manifest, or the extent to which their presence will simply scaffold existing power structures. There can be little difference between these purportedly emancipatory offerings and what’s on show at CES, bar a hammer and sickle painted on to the side of a robotic arm.

So those who fight for social equality are as susceptible to spectacle as anyone else. This shouldn’t be a surprise: complex technological systems have had wonder made of them for a long, long time. Starting with the Crystal Palace Exhibition of 1851, world fairs are the progenitors of trade events such as CES or World of Concrete – massive, immersive experiences designed to reach as large a public as possible.[29] They created a focal point to showcase new technologies and wonders at the civic scale – not just singular things but diffuse concepts. Echoing the showboating in contemporary events, wealthy exhibitors were more likely to be showing abstract offerings than defined goods. For industrialists such as Thomas Edison and Nikola Tesla, fairs were a place to make theatre of electricity. In Menlo Park in 1879, Edison created a display of incandescent lighting of such wonder that newspapers likened it to a religious revival meeting: grown men, moaning, falling to their knees in astonishment. To my knowledge, Oracle Systems has yet to achieve such an effect at any of its product launches.

The historian David E. Nye writes that a functionalist approach cannot explain why spectacular electrical lighting was so popular in the late nineteenth century, dryly noting that ‘America’s use far exceeded necessity’.[30] Some of this was a hard sell by Edison and Tesla in their ‘war of the currents’, competing to convince civic authorities of the large-scale political buy-in needed to approve standards and install all the infrastructure of wiring, switches, sockets, generators, transmitters, and more, for electricity to happen. The hustle was effective: a show of electrical force at the Chicago World Fair, where Tesla’s Westinghouse Company provided the power and incandescent bulbs for a showcase of wonderful lighting for

more than 27 million visitors, led alternating current to take the crown. This was not a black-boxed simulacrum of systems of the type on show at later trade fairs in the twentieth and twenty-first century, where visitors were invited to imagine what it would be like to prepare food in *this* kitchen or play e-sports with *this* console. This was electricity, live in the world.

Electricity was designed as spectacle, to be entertaining and to be experienced. It was deliberately crafted to sit in contrast to how electricity was experienced in the world outside the world fairs, where modern life was agitated by political corruption and rapid industrialisation. Motor vehicles careened chaotically down roads, and lethal aerial rats-nests of cables and live wiring were strung haphazardly between buildings, and God help you if you found yourself underneath them in a storm. In the expo, everything was beautiful and orderly and serene.

What I carefully propose for a systems engagement is something which can cause these perspectives to meet each other – tying together the strange and specific and often spectacular and sublime ways in which systemic forms punctuate our lives, but also to be attuned to the metaphors and allegories which shape these experiences. I am nervous about pushing more and different metaphors into the mix in the search for something to better describe the overall *thing* because metaphors, analogies, and fictions have meanings of their own, which then get mistaken for what the system actually is. Can we approach these things, collectively, together?

2

Scale

On 23 March 2021, the *Ever Given* container ship ran aground in the Suez Canal. Travelling westwards from Malaysia, the ship was buffeted by strong seasonal gusts of hot air – the *khamaseen* winds. The *Ever Given* was already travelling too swiftly for a vessel of its size in the canal, belting through the waterway to try to move through the wind rather than be blown off-course. At around 7:39 am, having been gradually pushed by the winds towards the east bank of the canal, the ship attempted to readjust, over-correcting as it did and suddenly moved westwards, displacing water as it swerved. As a car spins on black ice, so the *Ever Given* swung through the stream – stern one way, bow the other, its snout ploughing into the sand of the east bank. The ship was stuck and the Suez Canal – abutment to the flow of global supply chains – was blocked.

Like many others, the first I heard of the *Ever Given* was through social media via an image taken from the Marine Traffic site. On a regular day, the site maps the flow of maritime vessels across the world in real time, as soothing flocks of tiny brightly coloured rhomboids bopping across the oceans. On the morning of the grounding, a screenshot from the site showed simply a single yellow shape clearly wedged at an uncomfortable angle between two boundaries. This ship was not going anywhere. As the event was confirmed and news reports started to investigate the implications for global supply chains, the photos from Egypt began to arrive. First, a shot from above – the satellite image version of Marine Traffic's diagram, the sandbanks yellow and the ship a blocky Lego construct. And then, a photo taken from the ship stuck behind the *Ever Given*, which gave a sense of the heft of the thing.

Set against a grainy yellow sky with the washed-out colour palette of something bleached by sunlight, the photo showed the enormous vessel, hoicked sideways between the two shores – placed at such an angle to show the owner company's name, EVERGREEN, painted on its side. It is very hard to determine how big anything is in this picture: everything is lines, angles, and primary colours, and the ship's lettering is extremely clear and legible. There are no people anywhere in sight. Only the containers, which appear as small as Lego bricks but are stacked ten high and more, give a sense of how big this ship might be.

In the lower left of the photo on the shore, by the bow, is what looks like an inverted orange 'V'. A second picture followed shortly, taken from the perspective of this object. It's a yellow crawler excavator – a type of digger commonly found on construction sites to scoop out debris and soil. Balanced precariously on the bank, its extended arm reaches into the mud by the bulbous bow, its cabin barely higher than the ship's red waterline. It is a strange image to look at. First off are the mental gymnastics needed to cognitively reconcile the scale of the excavator down from how big we know it to be – the operator in the cabin is just about visible to give us a human form to latch on to. But even beyond that, construction vehicles are ubiquitously hefty boys. By the side of the *Ever Given*, however, this digger looks like a delicate insect picking away at its host's skin. This feeling of size difference is not one that can be described through numerical expansion, but one best expressed through a relationship.

But the picture is also unsettling; it is vertiginous. The comparative fragility of the excavator, treads slipping in the mud, make it vulnerable to the heft of the *Ever Given*: being sucked down into the undertow beneath the ship, maybe; or, one scoop of silt removed from the wrong pile, causing the entire vessel to fall sideways on to the digger.

As swallows migrate south for the winter, so memes follow popular news stories, and the *Ever Given* was a memetic gold mine. Some memes focused on supply chains; one compared Marine Traffic images of the ships flowing through the Suez with their movement around the Cape of Good Hope with the motto REJECT MODERNITY / EMBRACE TRADITION. The visual artist Daniella Baskin created a mocked-up dating app, Forever Given, to allow the single crewmembers on all the other ships, now also stuck in the Suez Canal, to find love ('Deckhand seeking crude oil tanker captain' is one possible pairing which the app's drop-down menus permit).

The ship itself was also the object of fascination: ‘Steal His Look!’ enthused one image, in the white-square style of a fashion look book, collating an expensive primary-coloured striped jacket, Dolce & Gabbana jeans, and some 99p self-adhesive wheelie bin stickers to allow you to dress like the ‘Cargo Ship Blocking the Suez Canal’.

Through this, the images which felt to me as though they carried the strongest resonance were those first two, of the ship itself stuck sideways, and the excavator trying to free it. They became extraordinarily popular templates for memes that had nothing to do with a crisis in global shipping but instead responded to the extremes of scale at play. The digger was ‘You, Trying Your Best’ against the bulk of the ship as ‘The Crushing Despair of the Past Year’. The digger was ‘A Diversity and Inclusion Workshop’; the ship was ‘Systemic Racism’. The digger was ‘Making Different Personal Choices’; the ship, ‘Structural Problems’.

In the days in which the *Ever Given* was stuck, it felt as though everyone on social media was responding, in their own ways, to a creative challenge to make a meme about the crisis. As someone with an emotional investment in gigantic machinery, it was wonderful; a personalised springtime festival of infrastructure. But I was also taken by other people’s fascination and response, which felt as though it went far beyond other similar supply chain misadventures, such as the grounding of flights in the wake of the 2010 eruption of the Eyjafjallajökull volcano. Part of this was no doubt the obvious dumb visual pleasure of ‘Big Ship Stuck’. But I also felt a crackle of something else; that the strangeness of scale in global supply chain systems, most commonly isolated as a big ship, or a large steel container, or a whole new waterway carved through the top of a continent, had somehow aggregated and slipped the leash, and was now running at full pelt into public consciousness.

Systems are a relational technology: they are defined by their ability to scale and, perhaps more importantly, their peculiar relationship to scale. Clifford Siskin defines this scalable property as a capacity to assume different sizes, meaning that a system could adapt both to changing situations and contexts, altering both the situation it finds itself in as well as itself.

From its Renaissance genesis, Siskin argues that this adaptable quality contributed to the persistence of the system genre over time. ‘Thanks to its

scalability,' he writes, 'system became a historical site for extraordinary intellectual aspirations, mixed with sustained attention to the form that sustained them.'[1] In part, this scaling permitted imaginative leaps, so that what was experienced as local had purchase on the universal: Newton's notions of gravity, for example. But scalability also ontologically shifted in meaning, from being concerned with creating a complete form, to a process of endless accumulation. An individual essay, for example, could provide an intellectual contribution to a large body of subject-specific knowledge, rather than having to 'scale up' to create a new field of knowledge in its own right.

These peculiarities around scale carried over through the re-emergence of systems thinking in the cybernetic movement. Here, as Valerie Olson describes, systems were seen as structures containing interconnected parts that could be imposed by analogy on to anything you wanted, regardless of size.[2] A fighter pilot is smaller than a fighter jet, which itself is smaller than a fleet of jets, but – in theory – the same systemic structure could be applied to all of them, simply stretched inwards or outwards. In the abstract, this intrinsic scalarity has a pleasing neatness to it. But – almost too neat.

In contemporary technology, 'scale' is presented as something aspirational and seamless; and the idea of scaling out a system of power has a longer and uglier history of control. If systems are structures which can be managed under the control of a larger purpose, scale can also be seen as a process which justifies grossly divergent distributions of power and resources.

In her memoirs of her time at Facebook – starting as employee fifty-one, ending as Mark Zuckerberg's speech-writer – Kate Losse recalls the time period very early in the company's history, when it was rapidly growing from something pretty small to something much larger – smashing user milestones, with Zuckerberg himself closing out their Friday all-hands meeting with a cry of 'Domination!' The shared passion of the company, then, was 'scale first, ask questions later', and she recalls her growing awareness of the implications of this ideology:

> My worry began to deepen when, around this time, Zuckerberg began using the language of states to talk about Facebook's burgeoning power. 'Companies over countries,' he told me once, as we discussed a blog post about Facebook's goals. 'If you want to change the world, the best thing to do is to build a company.'[3]

There is an intense friction between these two parts: the invocation to scale, and what it takes to actually make something scalable. An architect friend describes how her go-to line for critiques of student projects is: ‘Will it scale?’ This is not meant only as caution against ‘starchitect’ dreams of designing oligarch-worthy structures, but also as a test of students’ understanding of material qualities and construction methods.

Scale creates graduated differences in size and form. As Paul Dourish writes: ‘Scale and size . . . are not the same thing at all. If we think about simple massification, we might talk about the difference between a single cell and ten million cells, but that’s not the same as talking about a human arm. Scale is a dimension along which different objects arise; the arm exists as an object at one scale, the cell at another.’[4]

What do these peculiarities of scale feel like when they brush up against us? This might feel like a ridiculous question, given the obvious size of something like the *Ever Given*, one of the most gigantic ships in the world, built to the material limits of engineering possibility and sliding across the world through a channel released by a slab of land sliced out of Egypt. Yet this monstrous thing is not the system of global logistics itself or its homunculus, but only one outcropping.

Scale is what puts the ‘hyper’ into ‘hyperobject’: the point at which this ever-present *thing*, massively distributed across time and space, pokes through the mesh of its own existence and into the human experience. Its scalarity creates unsettling effects which warp and disorientate our attempts to perceive them. The stunted human sensorium is no match for the vast multidimensionality of the hyperobject; our cognitive limits are stretched by how it challenges the normative concepts of what an ‘object’ is and what it could be.

There is a gap, however, about how the presence of scale can be generative. For Timothy Morton, the human reaction to scale is one of passivity, highlighting how limited our capacity to engage with hyper-scale phenomena is. In their presence, however fleeting, we are shocked, stunned, disoriented, terrified. Morton writes off any value or meaning that might come in these moments. ‘Embeddedness in a world is no basis for ecological praxis and thinking,’ he states. ‘It means that no matter what my prejudices are, no matter what “world” I feel embedded in, the zones burn through them.’[5]

To which one might respond: speak for yourself. It is fanciful to imagine that these prejudices somehow evaporate in moments when complex systemic entities become perceivable; or, that in generating theories to cope with them, we will somehow be able to peel off from our own self-interest. This is a passive, incurious, and joyless position. Our experience within the surprising scalarities of systems shapes our understanding of them and shapes the systems themselves. Many of the *things* described as hyperobjects are human-made; we do not exist within them, but are part of them, from their constitution to their presence to their collapse.

And ‘we’ are many. You and I may find that hanging around with something unbelievably huge creates a gut-wrenching churn of sheer horror for one and rabid delight for the other. Even if we are both terrified, the cause of this churn might be quite different for us both, as will what we choose to do in the aftermath of this experience. ‘We’ may even be utterly blasé in the face of strange scales, but that indifference may have peculiar textures of its own and be worth digging into further.

Scale is political; it is social, and cultural. To simply swipe away the textures and even pleasures that come from rubbing up against it is reductive. It is boring; and, in the systems of maritime technologies and memes about gigantic ships, there are far more interesting questions to ask.

Had it not driven itself into a sandbank, the final – and literal – port of call for the *Ever Given* would have been Rotterdam; one of the few ports in the world capable of hosting a ship of that size. Wedged in the heartlands of South Holland, the city has the feel of somewhere that really likes big ships – that *really* likes big things. After the rows of pretty, slender houses veering over narrow canals elsewhere in the Netherlands – Amsterdam, Utrecht, Nijmegen – Rotterdam is a shock. Walking through the gigantic concourse of Rotterdam Centraal feels like exiting the maw of a huge whale; from outside, the building appears as an enormous, gilded chevron that has fallen from the sky and crash-landed into the earth.

The city is spangled with such buildings: gaudy modernist courtyard sculptures, Hulk’d up into a liveable size. On the canal is Rem Koolhaus’ De Rotterdam – a mirrored dinner set of a glitched-out cuboid, living its best life as the largest building in the Netherlands, where it was the proud 2014 winner of the ‘Best Tall Building in Europe’ Award. It sits adjacent to

Erasmusbrug, a cable-stayed bascule bridge crossing the Nieuwe Maas river – the largest and heaviest of this type of moveable bridge in western Europe, and which resembles a brutalist harp.

The city was flattened by bombs in 1944, providing the blank slate for building architectural-scale trinkets. But even by then, the city had folded itself around scaling. Rotterdam started small, as a tiny fishing village specialising in herring, built below sea level. Over the centuries it began a programme of what we might now call geoengineering: building dykes and dams to reclaim land from the sea and carving new canals to form the Nieuwe Waterweg. These activities were strategically mercantile; with its own waterway, Rotterdam could compete with the neighbouring, older, richer, and more influential municipalities, and eventually elbowed its way up to being the Netherland's second largest city – and largest seaport.[6] Wartime bombing took out the city's buildings and destroyed the harbour and wharves – ships that were docked there at the time sunk into the water to block the waterways. When restoration and reconstruction began in 1945, rebuilding of the harbour was prioritised over that of the city centre.

There's an amazing photo of the wharves from this time that I found when digging around in the specialist library at Rotterdam's Maritime Museum. In the foreground is the waterway itself with several men looking out across it to where, in the rubble, several dock cranes lie collapsed, their familiar silhouettes rotated askew to the sky; penguins knocked onto their backs. More than the ships themselves, cranes are emblematic of ports and shipyards as the tools which allow the work to happen. The motif of the dock crane repeats again and again throughout Rotterdam today, stencilled on to the pavement throughout the city.

Scale begets scale – forms shift and flex to accommodate bigness. Over the years, the ships sailing into Dutch ports have been changing shape and style, with large-sailed wooden ships making way for iron vessels with steam engines, which in turn transformed into the 'indurable monstrosity' of mega-container ships, as the logistics scholar Charmaine Chua has described them.[7] As ships changed, the mechanics of shipbuilding changed too. Steel plates were now riveted together – initially by hand, and then, as the rivets became bigger to accommodate the ships which were bigger, electrification was introduced to augment the strength of labourers. The rivets used to bind together the RMS *Oceanic* – the largest ship in the world at the time of construction in 1899 – were up to seven inches long and

weighed 3.5lb, and new hydraulic machines were introduced to amplify the speed at which workers could feed them through the sheets.[8]

Scale also requires – well, scale. To build the RMS *Oceanic*, Harland and Wolff had to also build a new and massive gantry crane that was sturdy enough to lift the materials needed for construction, and transport them down the long length of the hull. Photos of the Belfast shipyard where the ship was built show the underside of the gigantic vessel lifted and balanced on massive stocks, allowing workers access to its underbelly; while the inverted U of the crane straddles the top. It resembles an architectural turducken, an edifice nested within an edifice.

Organisationally, ships *are* buildings. As the engineering professor Horst Nowacki states: 'Civil architecture deals with the realisation of building objects on firm ground; naval architecture is concerned with the same creation process for floating objects.'[9] Not only are ships as gigantic as buildings, but the same operational processes must be used to construct them. Building and shipbuilding projects are among the earliest artefacts conceived, created, and shaped by humans through teamwork, requiring a specialised workforce, co-ordinated division of labour, and the requisite spaces and tools where the construction could occur.

It may be a stretch to think of something as massive as a crane as a tool, but at the scale of shipbuilding and maintenance, that's just what they are. Cranes are intended to amplify heft, and have been used for building things superlatively larger than humans for a very long time. As compound machines combining the simple machines of a lever and a pulley to multiply small forces upwards, the principles of cranes remain unchanged since they were put to purpose in the construction of Greek temples. Their silhouettes are now used on packaging from the Rotterdam bakery Maasstroompjes: a crane successfully hauling a rectangular cookie into the air.

A tool invites the question of itself: what is my purpose? In ports and shipyards, cranes are perhaps a more essential part of the environment than even the ships are. An enormous number of movies and television shows do scene-setting by showing characters walking underneath, or fighting on top of, shipyard cranes, as in the opening credits for *The Fast and the Furious*, the final showdown of *Iron Man 3*, and most of Season 2 of *The Wire*.

Cranes are responsive machines, an augmentation of the human scale and of human desire.

I'd come to Rotterdam that Spring to spend time with a company that did wire-arc additive manufacturing – think 3D printing, but with molten steel – who were based in a converted wharf in the old port; formerly home to a shipbuilding and repair company, Rotterdamsche Droogdok Maatschappij (RDM), which also specialised in submarines. After shipbuilding declined and submarines became too politically sensitive to yield many orders, the company shrunk, and the city of Rotterdam took over the shipyard.

Marc Levinson describes how, following containerisation and the emergence of mega-container ships such as the *Ever Given*, the exotic harbours of traditional ports were replaced by the 'remote carparks' of container ports.[10] In Rotterdam, the presence of the older port is viscerally imprinted onto the new city; and while Maasvlakte 2, the new fully automated container port, is based out on the coast at Hoek van Holland, it also marks its scent back inland. To get to RDM, one can take the waterbus from Erasmusbrug and spend the twenty-minute journey leaning on the railings at the stern, whatever the weather, being bounced through the repurposed arteries of the Nieuwe Maas – past the SS *Rotterdam*, a former ocean liner, now permanently docked and transformed into a hotel; past the skeleton of the *Delft*, an eighteenth-century warship now reconstructed in perpetuity only as its bones. It was from this position that I saw my first floating sheerleg – a gigantic crane attached to a flat waterborne platform, serenely moving down the river like some mecha-scale swan.

The company I spent time with was housed in old shipbuilding warehouses, now rebranded as the Innovation Dock. The place was described as a makerspace but was light years away from others of its kind. For me, makerspaces invoke, at best, an *Island of Doctor Moreau* affair, where folks have the space to make their strange beasts in an affectionately chaotic studio while a tiny 3D printer wheezes its guts out in the corner. At worst, they embody the thinnest type of technocratic dreams where 'technology' is a universal curative, and that same tiny overheating printer is a dragon's tooth, ready to be seeded to drive widespread economic recovery.

RDM's makerspace flipped this dynamic around – here were industrial-scale operations inside an old-fashioned factory. The offices and meeting

rooms for my group were built on to a platform strung up and suspended in the air, midway between the ground and the points of the warehouse roof. The platform could be accessed by climbing a terrifying grid-metal staircase which showed underfoot just how high up you were – one day, someone brought their large dog to work, and it clambered up the stairs quite happily but was struck motionless with fear at the top and had to be carried back down again.

The warehouse was filled with what were lightly self-described as ‘start-ups’ but would have eaten any dogfood delivery app for breakfast. Our workspace sat opposite the hydraulics consultancy Aqua Lab, which consisted of a massive raised rectangular body of olive-green water, somewhere between a public swimming pool with a wave machine, and a pond. Water behaves differently in the shallows. A huge ship may be built to withstand the brutal pressures of the ocean but once it moves into shallow water – a canal, to pick an example – the game changes; water which previously moved easily under the ship in the depths now has nowhere to go. To figure out *how* this water moves requires physical modelling. Because ships are big and the bodies of water that they move in even bigger, these shallow-bottom simulation tanks are still huge. Every so often, engineers in waders would head out into the tank to deposit a little boat on the water, before sploshing back to the raised control hub to get the water going.

That was the warehouse. For reading material on the port’s history and infrastructure, I headed back to Rotterdam Maritime Museum, whose library was everything you would want a maritime library to be: high ceilinged with wide windows that the light poured through. There was a locked vestibule where visitors could be escorted to gently paw through old maps and blueprints. The main room housed tall shelves stuffed full of leather-bound shipping registers from Lloyds of London going back centuries, but also books written by retired naval captains with enormous unresolved beef against the sea and everything in it. I assembled stacks of texts covering everything from ‘Assault on the Sea’ (subheading: ‘Essays on the History of Amphibious Warfare’), to ‘Design and Construction of Ports and Marine Structures’.

Reading through the stack, what became quickly apparent was that, if you didn’t use numbers, there were only so many ways that something could be described as big (ships), very big (ports), or extremely big (the

sea). This problem was exemplified in a photobook about Rotterdam which I had to put down at several points because I was laughing too hard and this was, after all, a library.

Through aerial photography, the book traces the many harbour basins threading inland from the North Sea which, collectively, form the port: the old petroleum harbour, the refineries, the mountains of dry bulk, and more. The photos are beautiful; the text is another matter. It begins fairly innocuously with descriptions of drydocks and floating docks as the 'Giants of Wiltonhaven'. But then: the yards where those offshore platforms are built are titled as 'Big, Bigger, Best'. Semi-submersible lift ships are 'Big Boys'; the Maasvlakte Oil Terminal has the 'Big Numbers'. After pages and pages of this, the repetition becomes blunting. 'One cannot fail to be impressed by the scale and diversity of the port activities,' say the authors.[11] To be gigantic is to be worthy of awe. The question left unanswered amid the hyperbole is: how did everything become gigantic? Ships aren't trees; they don't simply grow with enough nutrients and sunlight. Design deliberately manifests human intent. If maritime infrastructure is getting bigger, it's because someone wills it so.

As the photobook shows, the harbour basins of Rotterdam Port also deal with unusual deliveries. Every day, juice tankers (yes, they exist) moor at the European Juice Terminal (also real) to deposit their cargo of orange juice syrup, which forms the base for most of the concentrated orange juice in Europe. Global shipping may have been transformed by containerisation but still, liquid bulk commodities such as petroleum, fats, and orange juice concentrate, which can't be transported in a crate, constitute more than a third of maritime cargo across EU ports.

But for everything else, there's containers. Many of the ways that the *place* of Rotterdam has been intentionally morphed through geological and regulatory terraforming have also happened at other port cities around the world, under the auspices of the desire for scale found at the heart of colonial expansion and imperial circulation. And the shipping container embodies the radical changes to the globalisation of trade which has taken place over the past century.

Containerisation is more than the box: it is a vector of production and distribution.[12] It realises a form of logical thinking that prioritises quantity over quality – and it is bound up in a form of thinking that has its roots in

systems analysis. The ascendance of logistics emerged after the Second World War, when firms moved from competing mainly on the quality of their goods and services, to competing on how efficiently their offerings could be delivered.[13] Corporate profits had plummeted, and companies scrambled to find new ways to save money and reduce freight costs. New accounting practices such as total cost analysis allowed a collection of activities to be considered under the same frame: material management (that's to say manufacturing and purchasing) was no longer deemed separate from physical distribution, but part of the same system. 'Without a doubt', the geographer Deborah Cowen writes, 'the single most important shift that took place in logistical thought and practice in the early postwar period was the introduction of a "systems perspective".'[14]

These practices were sifted through the emerging field of business logistics, and specifically the work of Ludwig von Bertalanffy. Von Bertalanffy's framings shared common conceptual infrastructures with the systems thinking of organisations such as RAND, conceiving of systems as subjectively bounded entities in which individual components operated in service of a total function.[15] It also continued with the propensity for biological metaphors, positing a biological imperative for constant flow. Disrupting flow threatened the resilience of the system. Containerisation permitted the realisation of this form: standardised shipping containers enabled flow by radically reducing the time to load and unload ships. This in turn reduced port costs and increased revenue for manufacturers who, through just-in-time production techniques, could reduce inventories.

New physical infrastructure was also needed in order to allow massive steel boxes to slip seamlessly and rapidly through the world. Intermodalism – the use of two or more transport modes – was facilitated by containerisation, whereby a container could be unstacked from the top of a ship and re-stacked on to a barge or train. The size of the container has remained unchanged since being standardised by the International Standards Organisation in 1968. But, to hasten flow and increase profit, both the ships which carry containers and the cranes which handle them have become bigger and more plentiful over the decades. China's dominance in global trade can be attributed not only to its manufacturing capacity but that it also owns the world's largest container and crane

manufacturers and is third and second highest in terms of ship-owning and shipbuilding respectively.[16]

Logistics is profoundly entangled in militarised state forms; the art of logistics is the art of warfare. The modern ISO, or intermodal shipping container, was invented by Malcom McLean – but McLean developed its form by modelling it on the CONEX container, which had been designed by the US Army Transportation Corps to transport military supplies to Korea and Japan. Further back, in seventeenth-century France, *logistique* referred to the means of deploying munitions and provisions to military ends. Yet logistics are often overlooked in accounts of military history – not by its practitioners, who keenly described the importance of swift chariots (Sun Tzu), or finding means to keep soldiers well-fed (Napoleon). But for military scholars, whose writing and analysis are often characterised by masculine bravado, the real thrill of war comes from strategy and weaponry. Logistics are too banal to be worth writing about.[17]

There's something strange about the lack of interest in the dry logistical work necessary to create massive things, given the ongoing desire throughout human history to create massive things. It's a tension which the anthropologist Carol Cohn dug into in her gloriously titled essay from 1987, 'Sex and Death in the Rational World of Defense Intellectuals'.[18] After participating in a summer workshop attended by 'defence intellectuals' – the policy wonks and academics who engage with the calculative work of nuclear weaponry – Cohn became fascinated by the dispassionate and abstracted language that they used when discussing their work. She spent the next year as a visiting researcher in a university centre on defence technology and arms control, observing, untangling, and ultimately participating in its linguistical landscape.

Cohn's first surprise was the overt presence of extremely sexualised language. Masculinised sexual imagery has long been a part of warfare, from explicit phallic imagery to promises of sexual domination in arms advertising; but Cohn anticipated that, in the antiseptic space of academia, such language might be tamped down into subtext. However, it was text. Her colleagues spoke about nuclear weapons being 'irresistible', because you get more bang for your buck. Talk of 'vertical erector launchers', 'thrust-to-weight ratio', and 'deep penetration' was commonplace. Nuclear weapons allowed one to '[release] 70 to 80 percent of our megatonnage in

one orgasmic whump'; disarmament was equivalent to emasculation. The weaponry's size and destructive capability was a source of desire, but also still intimidating enough to require control.

Controlling the sheer scale of nuclear destruction also, unexpectedly, underpinned the use of language at the other end of the scale – the dry abstraction and euphemism, in which human death becomes 'collateral damage', and rich description evaporates into a miasma of acronyms. Yet this was not a cold-blooded decision by defence intellectuals to ignore, or psychically protect themselves from, the effects of nuclear weapons; but instead, a means for the speaker to be inculcated into a secret and powerful kingdom, in which mastering jargon afforded control over the art of war. To become fluent in technostrategic language is to not only to be afforded power over this system, but to embed oneself in it; when you yourself become the purveyor of annihilation, there is nothing to fear from nuclear warfare.

By the end of her year with the defence group Cohn was convinced that the subject of technostrategic language was not human lives, but weapons themselves. It was all a numbers game. The military scholar Thomas Power describes how these types of defence intellectuals used the concept of deterrence to explain why it is safe to have weapons of a kind and number that it was not safe to have.[19] In capital-S Systems, defence intellectuals are often positioned, cognitively, as part of The System – so deeply embedded that they're unable to conceptualise beyond an emotionless, abstracted, and perfectly informed calculus of mega-tonnage that allows them to think about the unthinkable. What Cohn discovered was that, through mastering this technostrategic language, her colleagues came to feel a sense of control and shared identity with the subject of their work – and eventually, conceiving of themselves as an entwined component of that system. As she explains, 'The enormous destructive effects of nuclear weapons systems became extensions of the self, rather than threats to it.' One becomes large, and lethal.

Laleh Khalili writes: 'Today, working cargo harbours are no longer central to the lives of port cities. They are often far away, behind layers of barbed wire and security – invisible, even forgotten.'[20] Rotterdam is unusual in this

respect. While the bulk of the city's container port has been moved ever closer to the sea, in the mouth of Hoek van Holland, other vessels continue to deliver goods into the harbours upriver. Rather than being contained and sealed off, the work of the port diffuses east along the Niuewe Maas and into the European heartlands, staining the city en route.

RDM sits in a peculiar little patch of one of these harbours, where a pretty Dutch village full of flowers and cosy houses with distinctive big red gable roofs is nibbled into on each edge by container yards. The yards themselves are closed to the public, but on one of my earlier walks around the area I found a bench on the water's edge, directly positioned midway on the perpendicular between two docks. I spent a lot of my breaks there with a *kroket* or a coffee, watching the repeating durational performance of the waterway as flat-bed barges arrive, stacked and unstacked, ready to be unstacked or stacked. In comparison with the out-of-service historical harbour machinery that sits in the Maritime Museum's yard, this dock feels at first as dainty as the nearby cottages; even its Konewald Gottwald harbour crane is painted a pretty baby blue.

Close up, the containers are always heavier and heftier than I expect. That is, until the crane starts to hoick one of them up into the air and suddenly this apparently safe and knowable thing is now rearing drunkenly around the container yard, swerving around on a cable as it swings over the barge and the water, truculently resisting the human control of the crane operator. The thought that races through my mind and my viscera at exactly the same time is 'JesusChristthatthingisfucking*enormous*'.

This feeling may be explained by the idea of the sublime. In his 1757 treatise, 'A Philosophical Enquiry into the Origin of Our Ideas of the Sublime and Beautiful', Edmund Burke writes:

> The passion caused by the great and sublime in nature, when those causes operate most powerfully, is Astonishment; and astonishment is that state of the soul, in which all its motions are suspended, with some degree of horror. In this case the mind is so entirely filled with its object, that it cannot entertain any other, nor by consequence reason on that object which employs it.[21]

Sitting on the little bench, metres away from this huge box which is being wanged around over the yard like a monster-scale thurible, held perilously in place by a yellow metal spreader, my mind has indeed been emptied of anything other than the possibility of being crushed if the crate loses its hold. This feeling – and it is truly visceral, with all the liquids in my body

feeling as though they've turned to cold seawater – is emblematic of what Burke describes as the sublime: a feeling which grows out of the ecstasy of terror through which people react to vast things.

Burke's formulation of the sublime grew out of an attempt to describe and rationalise that which was beautiful. What something beautiful would stimulate as love and relaxation, the sublime would invert – still maintaining a sense of awe and wonder, but now interweaving that feeling with terror. Scale was intractably associated with this formulation: small things could sometimes be seen as beautiful, but large things were off the table. 'It is impossible', he states, 'to suppose a giant the object of love. When we let our imaginations loose in romance, the ideas we naturally annex to that size are those of tyranny, cruelty, injustice, and everything horrid and abominable.'

Unable to rationally parse the difference between 'Neat! A really massive robot!' and 'Oh my GOD, we're all going to die', the mind collapses the two and locks into what Burke describes as the strongest emotion which we are capable of experiencing: a paralysing and overwhelming vortex of awe, wonder, and terror.

So, this feeling in my blood is nothing new, and in fact has been the subject of enthusiastic discussion and unpicking over the centuries. In 'Critique of Judgement', Immanuel Kant teased out further subtleties, arguing that because the sublime included both pleasure and pain, it was not the opposite of beauty. He instead carved out two further forms: the mathematical sublime, which described the moment of encounter with extreme magnitude, and the dynamic sublime, in which someone contemplates terrifying scenes but from a safe distance, allowing them to consider something as fearful without actually being afraid of it.[22]

Sublimity therefore was not a specific attribute of any object, but something which was created by the mind in apprehending it, inducing not only an immediate sense of fear but a complete awareness of human fallibility and insignificance in the face of something so enormous and wonderful and terrible. If – *if* – the mind was capable of coming back from this experience, it would do so renewed, invigorated by the superiority of the ego and reasoning over the senses.

For the historian David E. Nye, public reactions to modern technology – specifically, very large and extremely impressive technology – indicate a new sublime object; that which was human-made, large-scale, and driven

by complex engineering. This ‘American Technological Sublime’ is an essentially religious experience caused by direct confrontation with impressive, man-made objects in industrial society.[23] Nye is clear that these highly visceral encounters, which bring together awe, wonder, and terror, hold similar roots to those described by Kant and Burke: something made possible by the interplay of the physical presence of fallible human flesh, and something truly gigantic; something which could easily pulp the observer into a mush.

But it is also a socially constructed experience. There is nothing specifically awe-inspiring about any particularly big bridge or ship: one woman’s literal dreamboat might be another’s environment-damaging oil tanker. The hateful qualities which Burke annexed to enormous structures are still present in mega-technologies, and particularly more so if one is on the receiving end of the damage they can inflict. I might be quivering with fear and desire on the bench by the dock, but I’m also not the person having to wrangle the crane to get the boxes off the ground.

Familiarity can neuter technological sublimity. I am one of the newest people in the makerspace and the only one who doesn’t live or work around Rotterdam full-time, and there is a general air of expectation that once I’ve been here long enough my enthusiasm for really big things will wear off. I’m certainly the only person who wants to eat their lunch by the container yard; or even better, around the corner where I’ve discovered that the family of sheerleg cranes – Matadors 1, 2 and 3 – are docked. Everyone else is perfectly happy to have their food inside one of the local canteens.

Sublimity can also be strategically employed. In the Netherlands, similar forms of social cohesion around spectacular maritime technology are in play. On a trip up to Amsterdam one weekend, I visit another repurposed port, the Nederlandse Scheepsbouw en Droogdok Maatschappij (NDSM), an old shipbuilding and dry dock company which was transformed into a cultural quarter in the 1980s. The original buildings still stand, still filled with iron girders and yellow overhead crane cabins which now run over the tops of scores of artists’ quarters which run through the space. Like RDM, the NDSM architecture is so enormous that it feels like the warehouse has swallowed up a bunch of small studios and businesses, and still left room for dessert.

When I visit, the artist Henk Schut has built a sound work, *Right of Way*, up into the rafters of the warehouse which works with the acoustics

offered by the building's scale and emptiness. Sixty-four speakers are spread across a suspended platform up in the attic space, some freestanding on the floor, some strapped beneath swings. As we move across the space, the soundscape constantly changes and reforms as people ride the swings and footsteps echo on the poured concrete floor. I spend a chunk of time nearly falling asleep on a low bench above which another speaker is suspended. This is a system of noise and motion; not one which has been aggressively imposed onto the space, but one which seems to flow from and into it, recalibrating the enormous building into an acoustic space in and of itself.

Emerging from the building, I find myself in the middle of an open courtyard next to an array of white shipping containers which have, for some reason, been assembled into a free-standing arch. They appear to be securely attached but I still have that same edge of fear from the RDM docks when I stand underneath them. Not every old piece of maritime architecture is so lucky to be repurposed for the true nature of its form. Across the way is a familiar friend, another giant, fifty-metre-high shipbuilding crane. When I get closer, I realise that the poor thing has been gutted and uncomfortably re-engineered into a hotel.

I make the trip to Maasvlakte 2 on what happens to be one of the hottest days in Dutch history. The port is accessible by road, but I've decided to travel by waterbus to take in all of the maritime scenery over the waterways. It is holiday season and while I am heading to a gigantic civil engineering project, everyone else is off to sunbathe; one man has brought a massive beach umbrella onto the little bus from Schieden that we all fold and contort ourselves around. The beachgoers are smarter than me; the golden shores of Hoek van Holland sit directly opposite the port, which means that they get to sit under their canopies in swimsuits and eat ice cream while still taking in the views of cranes and containerships.

As we dock on the Maasvlakte peninsula, I realise that every other passenger has brought a bike. The marketing material for the port had stated that the visitor centre wasn't accessible by public transport, but I'd taken that as a challenge. Half a mile down the road, with an inland river of sweat running down my forehead under my hat, I realise that it may have been a warning. The path from the ferry terminal to the port is a solid stretch of road steering into the haze with oil barges moored to the right and a diesel

refinery on the left. Although every massive structure here looks like it's been lifted over from a Mars colonisation project, nothing is near enough to cast shade. Even the gang of seagulls circling overhead don't stay in one place long enough to protect me from the sun.

At the heart of the experience of the sublime is terror. The possibility of harm is not wrought through active malice but through scale differential. This little peninsula – and, by maritime standards, it is little – is not intended to be traversed by humans. There is no place to sit and rest. If (as I suspect will happen) I collapse having sweated all of the liquids out of my own body, it will be a benign and passive injury of the sublime.

But I keep going and, eventually, round a bend of the road to see the visitors centre for Maasvlakte 2 on the horizon. Calibrating how far it away it is impossible: the flat blue sky denies depth perception and some enormous objects on the right side of the road ahead are just . . . enormous. After another twenty minutes of walking towards them, they remain enormous and unchanged. Incomprehension is often the first reaction to something sublime, as proportion and scale become confusing to look at after a while.[24] Finally, the structures reveal themselves as gargantuan metal cylinders, stacked on their sides, but it does not hit me until later that they are the bodies of wind turbines.

And then, I arrive at FutureLand.

In 2006, APM Terminals signed a deal with the Port of Rotterdam to build Maasvlakte 2, and in April 2015, it opened for business. In the intervening nine years, the container port was built – not only through the construction of new buildings and machines, but by summoning up a whole new landmass, reclaiming 240 million cubic metres from the sea through dredging. While the name of its visitor centre, FutureLand, invokes the technological advancement of the terminal's full automation, the architecture scholar Victor Sanz also points out that this title is self-descriptive: the port, and its visitors' centre, are built of and on future land.[25]

Properly getting inside Maasvlakte 2 had been out of the question. Even for those who have full reason to visit the port for work, security is extraordinarily tight. Trucks have to book a slot in advance, and when they arrive their drivers are fingerprinted and required to pass through several checkpoints before being permitted inside. Resonant with what I'd realised

on my long walk up from the ferry, the port maintains a strict demarcation between what is built for humans and what is built for machines. However: FutureLand was there for the taking.

The visitors' centre at Maasvlakte 2 was never meant to be a permanent fixture. It was built as a short-term showcase when the port opened, providing a spectacular narrative sheen around the mega civil engineering project. The concept of the technological sublime has been sellotaped to mega-project management, to describe the thrill which engineers derive from building large projects that stretch the limits of technology.[26] The rapture of engineers and project managers wasn't expected to extend to the general public for very long, and yet FutureLand was an unexpected success and was kept in place.

This underestimation of public desire to be around massive infrastructure has a longer history. In 1987, to mark the fiftieth anniversary of its opening, the Golden Gate bridge was closed to traffic for one day to allow the public to walk across it and enjoy an evening fireworks display. Expecting a smaller crowd than when it opened in 1937, officials wildly underestimated the bridge's popularity. Crowds arrived before dawn and by the time the sun rose, a quarter of a million people were crammed on to the bridge, with another half million behind them; engineers hastily calculated whether the structure would hold (it did).

FutureLand emphatically does *not* let its visitors clamber all over the containerships or cranes. Instead, we tour the harbour in an air-conditioned boat, which is also equipped with a bar; a large group of retirees are on board with me, most of whom make free with the wine and beer once we get going. The first stretch takes us back around the headland, right back to where I first disembarked and, in the pleasant chill of the cabin, I am disconcerted to see that we zip down the route of that hour-long boiling walk in only a few minutes. The ferry swerves and scooches in alongside a COSCO container ship whose hull alone is more than twice the height of our vessel, let alone the shipping containers stacked eight high and twenty wide atop. The square footage of the deck alone would easily contain my little dock back at RDM. The curve of the royal blue hull rears up and over us.

I've only ever been near these ships on dryside, but as our little ferry bobs alongside it, the 'floating' element of this floating architecture is horribly present: a flashcard series of images passes through my mind of

how a rogue wave might hit, and how the highest containers might fall from the pile on to our boat; or, as the ship shifts in the water, we might get sucked down beneath the red stripe of the keel; or, the container ship might just tip slowly, sideways on top of us. Unfixed by land, the ship and its cargo are fearsomely dynamic. It's a similar sensation to driving on the motorway in hard rain, in a small car, and overtaking huge articulated lorries that feel as though they could swerve at any moment. The ship is bigger than anything mobile that I've ever been near, far bigger than the fuselage of the largest aeroplane, something so enormous that it could flatten us in its wake without touching us.

The prize of the tour though is not the mega-TEU docked ships with their muted colourways – bottle green *Thalassa Niki*, navy blue *Al Mashrab* – but the long-armed gantry cranes which reach out from shore to cover their full width and then some. They are gargantuan, necessarily many times bigger than the ships which they service; the horizontal strut of the arms sits at least twice the height of a fully box-stacked vessel. The shipping containers show the wear of their work, with sun-faded logos and rust creeping up the paintwork. But the cranes are clean – not only unmarked but fresh, box-fresh, painted that shade of bright duck-egg blue that if it were an item of clothing would instantly show stains.

We bounce across the harbour to where the MSC *Venice* is being attended to. From a distance, the ship appears as a series of blocks, the dark blue strip of the hull topped by a grid of coloured rectangles. Up close however, the fray and texture of human presence is visible; lifeboats, a lifebelt strapped to the railing, and on the deck above, a sign warning 'BEWARE OF PROPELLOR'. Squinting, I can finally see little people in hi-vis vests and hardhats, standing in the struts of the yellow spreader which captures the containers, working to unlash the boxes from each other to allow them to be individually carried upwards.

The cranes though have no such signs of life or differentiation; even as our ferry moves towards them, the effect is that of an eternal zoom into a CAD sketch – lots of straight lines and angles, all the way down and all the way up. The cuboid wireframe nature of their shape implies they could be built at any size, from nanotubules up to what's in front of me. This scalability is permitted, of course, by the lack of fleshy messiness which prevents an easy resizing. The little rounded cabin usually found under the

strut of the arm is missing, because these are fully automated cranes. There are no human operators here; there will never be any human operators here.

Maasvlakte 2 was constructed in service to flow, but its automation was shaped by scale. Driven by a desire to consolidate all of the container terminals to stay competitive, the terminal's wide port entrance and deep fairways were designed to allow the passage of Ultra-Large Container Ships (ULCS). Flow is sovereign: every ship, no matter how enormous, has to be smoothly and seamlessly stripped of or stacked with a mountain of containers and then sent on its way as quickly as possible. The quicker the turnaround, the greater the port capacity. New cranes were required, big and high enough to reach out and pluck the containers from these massive high-TEU capacity vessels as quickly as possible. The limiting factor in this choreography was people.

In investigating these new architectures of automation, Sanz identifies why humans were written out of the picture.[27] The human element was identified as the non-efficient part of the process. Bigger boats need bigger cranes, and bigger cranes imply that the cabin has to be faster. With a human operator, crane acceleration and deceleration are limited to prevent abrupt movements which accrue over time into muscle strain injuries. In a larger crane, vibrations caused by increases in acceleration would also have shaken the cabin more than any human operator could bear. The unprecedented height of the cabins meant that operators wouldn't be able to work with precision, potentially leading to damage of both equipment and any people working on them. As a result, humans have been almost completely excised from the mechanical work of the port.

Inside the cool of FutureLand are displays about the construction of the terminal where that gendered scale-fetish rears its head again. Alongside some enthusiastic walltext about the port basins is a sign describing the 'Sturdy Quays for Hefty Lasses' in the port. The sturdy quays are thick concrete sea walls, embedded 40 metres deep to provide structure and resilience to the reclaimed land, but I'm unsure whether the hefty lasses are the cranes or the ships. One room is filled with a forest of cardboard cutouts of people decked out in hi-vis jackets, sturdy boots, and trousers that have the sheen of some water-resistant treatment. Staring at the visitors with keen purpose, they are accompanied by signs offering up Maasvlakte 2 as an exciting place to work. 'A perfect environment for inquisitive people,' says one, but I feel the real reasons may be closer to those summed up by cutout

Rene, who enthuses, ‘Those big bad machines are a sight to behold.’ For some reason I’d assumed that the visitor’s centre would target adults with a thing for large maritime infrastructure, but of course kids love big ships too, and FutureLand pitches itself as a future workplace.

Port work can be vicious and harsh. In traditional, non-automated container ports, it is the human workers who maintain flow: loading and unloading ships, transferring containers to trucks and trains, piloting the little boats which guide the visiting bigger ships through dangerous harbour waters. And they can suffer, brutally, from it. Cowen describes how port workers frequently fall from heights, get crushed between machinery, are trapped under collapsed stacks, are impaled on metal rods, and are bodily severed when cargo shifts on ships. In the United States, port work is second only to mining in the number of industry workplace deaths and injuries. ‘The high stakes of logistics work is in part an inherent feature of labouring in an environment of big machines and metal boxes,’ she writes.[28]

In its automated state, Maasvlakte 2, although enormous, hits the limits of scaling; where the eternal fast flow of global commerce runs headlong into the problem that container ships are currently as big as they can physically be, while human bodies remain fleshy and fragile. But the tools designed to allow the two to meet in the middle favour the speed and scales of global commerce. At the automated port, humans are nearly fully, spatially segregated away from port labour, with crane operators located in a control room. Here, the behaviour and movement of the human form is closely attended to, blessed with both ergonomic design and natural light which gives reference to time (one of the sells for full automation of the port was that less lighting would be needed in the evening). There is no possibility of human control. Should the operating system go down, everything else follows with no way for people to intervene.

In June 2017, this is exactly what happened when the Port of Rotterdam was attacked with the ransomware NotPetya. Exploiting a weakness in older Microsoft Windows operating systems, the attack originated from a piece of Ukrainian accounting software – revenge of the spreadsheet – wiping files, intercepting passwords, and performing activities usually done by a (human) administrator. The malware entered via APM’s parent company, Maersk, the logistics giant that used the accounting package, hijacking two of the container terminals. The software-dependent cranes

and trucks were out of action for weeks, with containerships sailing to nearby ports to be unloaded.

The ransomware damage to Maasvlakte 2 was only collateral in a larger battle between state actors with the intent of data destruction, not financial shock. Isolating the networked infrastructural systems which the port runs on and which are managed by multinational companies would be unattainable, yet action at the local level is insufficient. This, Sanz notes, is the result of the asymmetrical agency between humans and technologies: 'If humans are excluded, in the case of malfunction, buggy behaviour, or hi-jacking, we cannot correct or intervene – at least not in any way other than by means of a drastic stop and pulling the plug.'[29]

Maasvlakte 2 has been built, from seafloor up, to resonate with the scale of global commerce and in doing so shakes the human scale off. The twistlock and lashing that we saw on the side of MSC *Venice* is one of the few parts of port work that resists automation; lashing containers together so that they remain stacked in place, no matter what the motion of the ocean. Lashing gangs have tools which use compressed air to tighten and loosen the lashing bars, and which require complex manual manipulation. It is one of the most dangerous jobs at port, but unlike the body-shocking crane operation of mega-TEU ships, it is unlikely to be automated any time soon, or ever. Cranes can be automated piecemeal, port-by-port, with injury to operators also being squared against damage to cargo. But when lashing gangs are injured, the cargo remains intact; and to fully automate lashing would require a complete design of shipping vessels themselves – impossible to imagine that the entire global system of containerisation would be dismantled, from the top, to protect the bodies of these workers.

The most adorable container yard in Rotterdam can be found up on the the roof of the Maritime Museum. The quayside crane is egg-yellow with its silhouette rendered into that familiar giraffe-like form: long-necked with an inquisitive head and a rotund body for the cabin. The bulk cargo is made up of spongy blocks, wrapped in fabric. Several stevedores in hard hats and hi-vis vests nonchalantly stride around the yard, tossing barrels around and confidently manhandling the crane. I'm not good with size, but I'd be surprised if any of them are over six years old.

De-scaled and de-fanged, there is little of the violence of global trade present in the playground. But this is not a basic reduction: the wooden

‘machinery’ is painted in the same primary colours I’ve seen at RDM and Maasvlakte 2, and, even when shrunk down, their angles and silhouettes call, somehow, to the work they could potentially do. The soft containers invoke the heft of their larger kin, with weight limits, a sturdy door handle, and thick ‘steel’ ridges printed down their sides. The protective gear implies that there is something to protect against. Whatever is large is clearly not here, but it is somewhere.

Dress for the job you want not the job you have, goes the saying, but by the time these micro-longshoremen reach adulthood, it’s unlikely that the crane operating job they’re currently dressed for will exist. In a control room with air-con and big windows, their workwear will reveal something else about the scales of the mesh they’re working – operating – in; that snarled and snarling system still flexing its protuberances through the tells of its presence.

3

Legacy

The map arrives in a massive cardboard tube big enough to hold at least three large cats. I hustle the tube down the steep hill from the Post Office and into a café for warmth, coffee, and, at the back, a large table where I heave the paper out of its casing. Unfurled, the thing flops and sprawls over the table's edges, easily three metres square. Here is the entirety of European airspace: every single country, every single border, every single route, and every single militarised airzone, all overlaid. Imagine a magic eye picture composed of geometric shapes and criss-crossed lines all multiplied and layered over each other, except that when you loosen your gaze to induce double vision the only thing that jumps out is maybe the outline of . . . France? And then everything collapses into a migraine.

My contact at the European Organisation for the Safety of Air Navigation – aka Eurocontrol – had promised that this map would be 'visually striking', and it certainly is. It is also impenetrable. Its arrival marks the culmination of an intense period of research for an art installation that my collaborator Wesley and I are doing around the presence and politics of airspace systems. For weeks we have been sifting through the cartography sections in Eurocontrol's 'Skybrary' (yes), trying to assemble the right collection of maps that will perfectly and completely describe the airspace over Belgium. Each individual map shows a distinct area of airspace, but the point is that each map also simultaneously exists with its kin. The block of air extending upwards from the borders around Belgium contains, at different heights, the controlled spaces that commercial pilots are permitted to fly through at different points of flight, the super restricted spaces that only military planes are allowed through, and liminal areas which slip in and out of control depending on times of the year.

Some zones are specific to height – planes cruising at altitude stick to the air routes of the top slice in Zone A, a long slender strip 18,000 metres above mean sea level which wraps around the world. In the controlled areas around airports, during takeoff and landing, planes will move up and down a funnel of stacked zones consisting of a narrow neck at ground level which expands and widens up into the sky.

‘In thinking about airspace, it is necessary to think in three dimensions,’ my Eurocontrol contact advised me. Other people in air traffic control have encouraged me to think of airspace like a layer cake, but looking at individual maps and the cross-sectioned images from air traffic service websites brings to mind one of those ‘hidden-inside’ cakes that turn up on television baking competitions – a seemingly regular cake from the outside, but cut through it and you’ll see a surprise heart or flower or militarised flight zone tucked into the sponge.

Topographic land maps use cartological realism, with lines and shading giving a sense of the shape of the unadorned earth that the map represents. The massive floppy airspace map has no such niceties. Every line is slapped on top of every other line. Europe is peeping out from underneath the tangle but there are no signs of life: no city names or towns, no mountain ranges or rivers. Land is yellow and water is blue but countries are not named, only demarcated by thick border lines. Those borders and the zones of airspace are the main human-made forms on show, defined through international law. There is no *there* there, only lines defining immaterial blocks up in the air.

And yet: barrelling across these chunks of air are massive slabs of metal, massive *flying* slabs of tons of metal travelling at hundreds of miles an hour; thousands of them all packed into those same chunks of air and spiralling around the same landing hubs. The pilots of every single one of those planes must adhere to the map’s dictates to avoid catastrophe, but the map’s authors must also ensure that any changes they make, no matter how slight, must also cohere with every other element; a Jenga hypercube where if one brick is removed, the entire stack collapses.

The map on the table in front of me is empty, but it does not represent the air. It represents absolute control.

Airspace maps are an empty stage: the conditions for flight are set up, but now we wait for the performers to arrive. To see the full show, it’s better to

turn to interactive tools such as Flightradar24, an online aggregator which collects the movement of airborne vessels in real time and overlays them on to a regular map. Each vessel has its own icon to indicate whether it is a plane, helicopter, or – if you're lucky – zeppelin, which you can click on to see the flight path; and, under each one, Flightradar24's designers have also introduced a skeuomorphic shadow. Zoomed out, the clusters of wriggling planes at each airport resemble cats around a feeding bowl. Flightradar24's reading protocols demand that the planes remain in motion while the world underneath is still.

'THINK ABOUT THIS', demands a textbox in Donella Meadows' 'Thinking In Systems': 'How do you know whether you are looking at a system or just a bunch of stuff?'[1] If it has parts which affect each other to produce a collective effect which persists over time then, yes – it's a system.

Systems have temporality: they are defined by time. Comprehending how systems move through time – or, how time moves through a system – is challenging. While visual forms such as diagrams and maps are more equipped to take systems on in their own terms, they are constrained by their need to capture some aspect of them and make it legible. Graphs are pretty solid at depicting behaviour over time, rather than focusing on individual events, with the horizontal axis pushing out towards the time horizon, raising questions about what came before and what is yet to come.

From a cybernetic reading, time occurs in a system via the series of checks and controls which allow the system to maintain its persistent behaviour. I cut my finger: my biological defence feedback systems kick into play to clot the blood with platelets, fight infection with white blood cells, and strap strands of collagen across the wound to assist tissue repair. The skin heals, my body returns to its desired state of health – and, if I cut my finger again, the whole cycle begins anew. When we talk about feedback mechanisms being used to control systems, what we are really talking about is a constant desire to keep things just as they are until inevitably something comes along which throws the whole thing out of whack (the heat death of the universe; I am hit by a truck). This cybernetic legacy allows us to conceive of a system existing out of time, containing the means within it to learn and adapt in order to maintain equilibrium, buffeted along through outside forces but ultimately a self-reinforcing ship-in-a-bottle. Feedback delays may mean that by the time a problem becomes

apparent, it may be more difficult to resolve, but the control mechanisms abide.

In television, a ‘bottle episode’ is one designed to be shot on the lowest possible budget, often keeping its characters in a single location to do so. In sci-fi, they can be used to claw back money from the more special effects-heavy parts of production. With only one set, these episodes can often be drawn out and emotionally intense, relying heavily on both the premise and dialogue set up in the script, and the actors. By the time a bottle episode takes place, the world in which the show exists and the internal logics that it runs on has been well established and much of the drama is wrought from the tight focus on a small part of this place, and the knowledge that the rest of the world is still there. A bottle episode provides a respite from time, but time still claws away outside.

A closed system can be claustrophobic. Placed behind high walls, feedback gears grinding away towards an eternal purpose, systems can feel as though they have no history but have appeared from the ether to persist perpetually. The behaviour that they twist towards just is. Yet everything comes from somewhere. My injury response has emerged through hundreds of thousands of years of iteration, and is primed towards my survival.

In human-made systems, at least some of those behaviours are intentionally written in from the beginning, designed into the mechanisms intended to steer it back to its desired state again. You can’t beat The System, not because it’s more powerful than you, but because it contains within it the means to persistently revert to its mode of an articulated and assertive dominance.

Other habits emerge too over time as the thing rolls into action. Unbundling the difference is half the fun (or, if you’re a systems manager, the night shift). ‘Learn its history,’ Meadows implores; ask people who have been around a system a long while to tell you what has happened. Watch it do its work. Tracing time back through a system does not simply involve seeing its behaviours spin backwards but also running your fingers over the points and nodules that stud its past; to feel out why the thing does what it does. And this is not an easy or linear process. When we talk of systems happening all at once, this doesn’t mean that each system contains within it a series of many identical gears, all spinning together in synchronicity. Instead, their nested parts operate at different timescales and

rhythms: short term oscillations and periodic outbreaks; long cycles of succession; culmination and collapse.

Reading about how time nests and bends within complex systems and the constant slingshots back to 'normal' brought to mind Alexis Lothian's work on queer temporalities and utopias.[2] In theory, as their name suggests, queer utopias have the potential to be radically anticipatory, challenging norms around what it means to exist within socio-economic structures. In practice, however, Lothian notes that the political reality summoned into being by US-based queer activists in the 1990s assimilated into existing social and political structures – real transformation was bypassed and the structural realities of race and class ignored. Their activism had become trapped in a gravity well – a bottle episode – of its own making, bound by structures that seemed immutable; and in doing so, reproducing and enforcing existing power structures into the future – the reproductive family, the belief in markets. Rather than truly making things otherwise, the System abided.

Here's a contradiction: although I love aeroplanes as singularly beautiful feats of engineering, I dislike flying. I am so, so scared of heights. The best part of any flight for me is the beginning of the descent when you know at least that you're coming down. Although I prefer a window seat, my ideal flight is one that takes off at night, flying through the dark where the only indication of the land miles below is the twinkling lights of cities (but I also want those lights to be there because I am also terrified of flying over huge bodies of water). A daytime flight which carves through or sits atop the cloud layer can also be pleasant. On long haul flights the boredom can sometimes numb out the fear so I can take pleasure in looking across the frozen fields of Utah. I love aeroplanes but would have been a terrible pilot.

In early flight, this view down was the only one that mattered: the movement and navigation of vessels was wholly dependent on what the pilot could see. The first aeronautical maps were produced not for aeroplanes, but for their predecessors: balloons and zeppelins. Oberstleutnant Hermann Moedebeck, a Prussian military balloonist – a real job in the late nineteenth century – is widely acknowledged as the forefather of contemporary airspace mapping. In his 1888 article *'Ueber das Landed mit Ballons'* ('On Balloon Landing'), Moedebeck argued that what matters for someone navigating from above is not the same as what

matters for navigating on land. Aerial maps needed to show suitable landing points, and the types of winds from which they offer protection. They should incorporate acoustic data for when eyesight wasn't enough: in an open-air vessel, 'sounds make it possible in conjunction with the map to orient the course of a free balloon during night flights'.[3]

Moedebeck died shortly before the first International Commissions on Aeronautical maps, held in Brussels in 1911 and which set the pattern for international collaboration which characterised subsequent decades of airspace mapping.[4] By this point aeroplanes were ascendant over inflatables; and, after the carnage of their testbed during the First World War, the push for maps that greater served the specific need of pilots came to the fore again. At the first international congress on aerial navigation, Lieutenant Colonel E. F. W. Lees argued that aerial maps needed to be based wholly around the requirements of airmen, whose view was positioned vertically downwards: 'He does not require much in the way of names but he does want the characteristic geographical features and all artificial features of special value to stand out clearly. Shape is of essential value to the airman.'[5]

In her essay, 'Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective', Donna Haraway uses vision as a framing device to relocate the abstracted, unrestrained, conquering 'view from nowhere' in science, to a sensory, embodied perspective. Although this approach is intended as metaphor, Haraway conflates the power dynamics of with and without, into high and low; above and below. This is understandable: gods are often positioned as emerging from on high to see all and pass judgement. Height denotes power. The view from below is the perspective of the subjugated: it is limited, constrained by what can be seen at ground level or lower, at the 'great underground terrain of subjugated knowledge'.[6]

Haraway's point is that there is no disembodied view from nowhere: even at the highest point, vision is embodied and sensory. For a pilot, flying high above the ground offers a specific position, location, and situation from which to look down – and that view is partial and limited. An elevated perspective is not a totalising one; but, as the early days of aeronautical flight indicate, the view from above is also partial. It flattens hills and mountains; it makes large geometric shapes out of bodies of water. If clouds

roll in, vision is obscured; and at night, without light, the view is gone. ‘Location is about vulnerability,’ Haraway writes, and for early aviators, flying high and solo without radio connectivity or refined instruments, flight was precarious, a deadly prospect. The limits to vision were the pilot’s own eyes. Haraway’s techno-scientific vision – the satellite surveillance that would later form the bedrock of the construction of airspace – is, indeed, far more superior to the limited god’s eye view that early aeronauts had: suspended high in the above, but still constrained in vision by the limits of their own retinas.

Two main issues shaped aeronautical mapping. First, as Lees noted, aeronauts had very different needs to their ground-based comrades. When seen from the air, the perspective of the ground changes: hills become flat; railways and roads turn into thick lines; the strange shapes of lakes punctuate the landscape. These shapes became critical points of navigation which could be identified by sight and cross-referenced to a map. Pilots had no need to know the height of a landscape unless it was extreme, such as mountainous areas where one had to navigate across valleys and passes.[7] Topographies were out; geometries were in. One of the first actions of international co-operation in airspace mapping was to use rows of red crosses to mark electric power lines. In one region-specific Belgian map, the red roofs of the German town of Lindau were added as ‘notable landmarks’ which could be identified by pilots during flight. Dependent solely on eyesight, pilots flew close to the ground, and kept flying predominantly to daylight hours.

Second, pilots *flew*. On land, one might take a moment to pull out a map and orient oneself. No such option was available to people wedged into a tiny cockpit – which initially was also fully open to the elements – who had to keep the vessel in the air while wrestling with a large and unwieldy sheet of paper.

Framed as a challenge, nothing about this seems too complicated: ‘Make maps specifically for people trapped in a tiny box at high altitude who depend solely on their eyesight for navigation’ would be a standard brief for any graphic designer. Yet it took several decades before genuinely new aviation charts arrived. Instead, early airspace maps were made by printing aeronaut-relevant information onto existing maps. State-led mapping of land and sea had been started several centuries earlier by the British and US governments, in response to territorial colonisation and fears

of invasion; later, during the First World War, aeroplanes themselves provided a cheaper and more accurate means of gathering data through aerial photographs, stimulating the production of information to aid air navigation.[8] But by the time that planes and balloons came along, standardised maps were fully established and it was these charts that were used as the basis for airspace navigation. British aviators used Ordnance Survey maps overprinted at various scales. Initially, aeronautical information was added in red, and then, from the 1950s, in blue.[9]

Concerns had already been raised about whether these extant maps truly served the aeronaut; one of the major rows at the first international congress on aerial navigation was whether the Mercator projection was best suited to aerial mapping, as it distorted the polar regions. Similarly, use of overprinted maps led to many of the colour conventions of nineteenth-century mapping being followed in aviation cartography without consideration of their appropriateness. Use of brown for contours and blue for hydrology, for example, might convey their pictorial qualities, but didn't necessarily give the most appropriate emphases for features to be viewed from the air.

What might structures look like if they diverged from their first purpose? One of my favourite pieces which considers this is Sascha Pohflepp's 2009 artwork, *The Golden Institute*, which explores what energy infrastructures might have looked like under an alternative history of the USA. Pohflepp rewinds the clock to 1981 and asks, what would have happened if Jimmy Carter had won the presidential election and subsequently pursued his tranche of radical environmental policies? What would power infrastructures look like if all the cash and resources that had been ploughed into the space programme went into alternative energy instead? Pohflepp answers these questions by building the prototypes of these systems: not dry engineering blueprints, but the models and rendered photographs more reminiscent of classic futures scenario planning. The fictitious 'Golden Institute for Energy' at the heart of the work is intentionally comparable in scope and architecture to the RAND Corporation.

In one prototype, a composited landscape painting depicts the city of Golden, wedged into a valley, as artificially engineered clouds and gigantic lightning bolts loom overhead; the weather modification is actually a boon, and the lightning is harvested to power the city. Another model is of a diner,

Chuck's, sitting beneath the Interstate 5 freeway in California. As they exit the freeway to Chuck's, drivers – now in cars kitted out with magnets – must drive through induction coils which gradually slow the vehicles with the Lorentz force. The system harnesses the energy which would otherwise be lost when cars brake; the coils are typically operated by a franchise such as Chuck's where drivers can get free coffee for participating. Both the painting and the model would fit seamlessly into the office suite of any C-level executive. The ideas are manifested with the springiest of textures and acute attention to detail. One part of the work is a replica of an office at the Institute, complete with plug socket on the wall – except that this installation was in London, and the socket is a classic US standard one.

Pohflepp positioned *The Golden Institute* as the earth-bound equivalent of NASA: a different starting point from the political, often militaristic intents of many technologies, which unfolds into a new direction. From their ballooning origins, aeronautical maps had military purpose baked into them. Warfare drove the development of the first US federal mapping, demanding accurate representation of terrain.[10] After the First World War, the Army Air Service began developing air navigation strip maps documenting prominent features along army air routes; unlike area maps, strip maps were smaller, making them more suitable for the cockpit and depicting a commonly flown route. Combined air-and-army maps were made to enhance the interaction of ground and air crew, with more topographical information than airmen strictly needed.

Prior to the Second World War, it became necessary for military maps to be legible under artificial cockpit lighting. Military agencies explored the use of experimental strip maps with night maps printed in red for use under the UV lighting preferred by US and German air forces, and with fluorescent inks. By contrast, nations that used red cockpit lighting, including the RAF and US Navy, used blue and black print for overprinting navigational informational, establishing the convention of dark blue aeronautical overprint. Red was only used for features not required at night, such as roads; woodland was overprinted in bright green because of its navigational significance.

Materials, too, came into play, including transparent sheeting and treated papers capable of withstanding rigorous flight conditions. Survivor and escape maps were printed on to slippery acetate rayon and rubberised cloth, thin and malleable enough to be hidden in the lining of clothes or

inside vinyl records. New maps were made for martial purposes: target maps for bombing, drop-zone maps of airborne forces, maps for close co-ordination squadrons, high altitude maps for fighter aircraft.

Wartime maps seeded the common international air maps that form the basis of the beast that I received from Eurocontrol. By the end of the Second World War, international commercial flight was on the cards, requiring global maps, and world aeronautical charts were compiled and published by the US, using material from allies. Decades on, several map series continue to use the original wartime colour specifications as changes would be time-consuming, costly, and require international agreement and collaboration. Once a complex knot is tied, it becomes difficult to untangle it.

What might aeronautical cartography have been if it had not been seeded in martial frameworks? Even area maps and the identification of local and national borders arose from the desire of states to identify and assert control.

For a brief period in the 1920s, an alternative system was in play: not from the military, but from the US Air Mail service. Like their military counterparts, air mail pilots were limited to navigating by sight; but, to deliver post at speed, aviators had to be able to fly across transcontinental routes through the night. Rather than creating maps for the cockpit, the US Postal Service created maps on the land itself: ground-based landmarks dotted out across the way. Threaded across the route which spanned the United States, east to west, was a series of rotating searchlights set in 50ft-high towers. Like a stream of lighthouses, spaced about five miles apart, airmail pilots could navigate their way through the night, by the light. To ensure that they were flying over the correct beacon and not some random searchlight, beacons were also accompanied by massive concrete arrows, up to 70 feet long, painted yellow and set into the ground – bright and huge enough to be seen from the air, and pointing the way.

Beacon cartography lasted for only a decade. It became redundant in the early 1930s – not because of any emerging wartime issues, or conflicts with state mapping. Instead, radio and radar communications emerged and reconfigured flight itself from an isolated process into a networked information system. Not needed further, most of the beacons were torn down or abandoned.

To make a live flight map that moves in real time, my collaborator and I have to track the vessels moving through the sky in real time. Airspace is not a road: not only do we need to know the speed at which each airship is travelling together with its latitude and longitude location, and how this changes moment by moment to give movement, we also need to know altitude. We also need to know which vessel is which, to stop our map from being a murder of anonymous points in the air and indicate instead that each plane has an identity, a purpose, and a trajectory.

The easier way to do this would be to access the insides of a flight tracking service such as FlightRadar24, which already has all these data streams, jack them into visualisation software, and then let the code do the heavy lifting. But this would be a mediated form of seeing. We would have no direct access to the original information collected by the flight tracker, and our installation would be completely dependent on the service running smoothly. But we are not only interested in the data: we want to know how much access *we*, two civilians, have to this data which defines the structure of the sky above us.

So, this is how we do it.

Every plane is essentially an airborne radio station, its fuselage and kit studded throughout with electronic instruments and operational sensors that detect where the vessel is, how it's behaving, and what it experiences in any given moment. The Air Data System, for example, does exactly what it says on the tin, capturing data on the pressure and density of the air that the plane is moving through, and the different types of speed – vertical, calibrated, true, and Mach – which the plane exerts. Some sensors detect how the plane rotates and rolls relative to its centre of gravity; others, made up of accelerometers and gyroscopes, pick out how the aircraft is moving relative to the earth below it. Much as a patient in an operating theatre is constantly monitored by an anaesthetist who checks that the patient is stable – that is, unconscious but breathing, and maintaining all vital signs – so a plane's sensors tell the pilots that their gigantic steel vessel is both speeding through the air and doing *just fine*.

Some of this information is for the benefit of the pilots only; but some is also for air traffic control. Together with the plane's own personal call sign, data about the plane's position and movement is periodically and freely broadcast out from the plane on the 1090 megahertz frequency. The system is known as Automatic Dependent Surveillance Broadcast – ADS-B to its

friends – and was set up as a replacement for secondary surveillance radar for air traffic control stations. Its information is generally more accurate than that collected by radar, and the set-up is easy: all ground staff have to do is set up a radio antenna and wait.

ADS-B signals can be disrupted by big buildings below, a mountain range, or just through horrible weather. But crucially, they can be directly detected by anyone on the ground with the right radio equipment, such as my collaborator and me. We have an antenna, and we have software-defined radio: a tool that uses software to process radio signal in a way that was previously performed by hardware, and which allows us to quickly unpack all the information contained in the ADS-B broadcast. Once you have those parts, then you can patch them into the visualisation programs, and then you can make your map.

For the mapping of airspace, the most crucial part of the technical assemblage is not the sensors. Vital though they are to flying, their information is still contained in an isolated system of the plane and its pilot. To move from flight to airspace, what is needed is communication at distance; what is needed is radio.

The first era of flight was wildly unrestrained – what former air traffic controller Helen Parke-Wall described as a ‘rodeo in the sky’.[11] Imagine any teenager you’ve ever known getting the keys for their first car. Now imagine that all those cars are high up in the air, careening around in three-dimensional space with no way to communicate to each other apart from flashing their lights. Keeping them from crashing into each other will absolutely be a challenge. ‘How do you get a bunch of independent hard-headed devils to get in line for takeoff and landing?’ Parke-Wall asked. Until radio emerged, the first airfields relied on something big and visual to bring pilots in safely to land. At St Louis, the local community hired a man who went out into the middle of the airfields with his own seat and then sat down and waved coloured flags to indicate whether the incoming planes should touch down or not. Emulating beacons, signal lamps were also used: originally pioneered by the Royal Navy, the lamps produced a pulse of light that, combined with colour signals, could be pointed at specific planes to bring them in to land.

Radio changed all of this. Without radio, a pilot could use aeronautical maps to mark out their route, but they would still only be a single point traversing the landscape. But a pilot with a radio transmitter became part of

a network, folding time and space to allow them to see and communicate past the eye's horizon. And a network can be mapped and controlled.

Wireless telegraphy had been used successfully on ships for a long time by this point: as solo vessels, moving through uncertain and dangerous waters with the direction of travel marked out by compasses and a bright map of beacons – the stars above – ships were the perfect test bed for a technology which allowed communication beyond the immediate realm. One of the first wireless distress signals, 'CQD' was created in 1904 by the engineer Guglielmo Marconi, specifically for ships in distress. Decades before radio equipment became small enough to be built into cockpits, the British shipping company White Star Line had hit the headlines after a communications snafu on board their largest steamship led to the wireless operators missing crucial messages from nearby ships about an incoming ice field on the transatlantic crossing. The ship – RMS *Titanic* – struck one of the ice floes and sunk. With more than 1,500 lives lost, it was one of the deadliest peacetime maritime disasters in history – and one which could potentially have been avoided had the wireless operators not been overwhelmed and confused as the catastrophe unfolded.

Ships today, like planes, still use radio to communicate. In an earlier project, my collaborator and I wanted to explore whether we could directly intercept their signals too, so we spent a morning out on Brighton beach with a laptop loaded up with SDR software and a massive antenna to see what we could pick up. It didn't work; much like picking up signals from planes involved installing an antenna as high as we could get it, it turns out that line of sight for radio matters, whether horizontally or vertically. The only way we were going to get radio signals from ships was by heading out into the water, right into the middle of a shipping channel.

But the legacy of ships on aeroplanes goes far beyond wireless. The sea imprints on the air. In *Skyfaring*, a lyrical account of flight, the Boeing 747 pilot Mark Vanhoenacker teases out how the development of airspace is contained within maritime culture.[12] When you buy a ticket for air travel, the plane that you travel on will be one of a *fleet* managed by your airline carrier. When you walk onto it, you'll find yourself in the *cabin*, together with the other passengers. You travel in different classes, whose areas are separated by *bulkheads*. Your inflight meal will be prepared in the *galley* and will be served to you by *crew*.

Up at the front is the cockpit – sometimes referred to as the *bridge* or the flight *deck*. There you'll find a *yoke* and *tiller* for steering; at the back of the plane is the *rudder*. The people who guide the plane from here, and assume responsibility for its travel, are the pilots; the co-pilot is designated as *first officer* and the captain may be called *Skipper*. They wear navy blue outfits with a sharp gold trim, an aesthetic intentionally chosen to mirror the full dress uniforms of the US Navy. These outfits were designed by Juan Trippe, the naval aviator who founded Pan Am, and named his flying boats 'Clippers'. Similarly, the Boeing 747, with its distinctive silhouette and bulbous snout, was intended as an aeroplane with the stately majesty of ocean liners, and which could conquer ocean lines in a single flight. Engineers who create these vessels are experts in aero*nautics*, and perhaps the only reason that aeroplanes aren't called airships is that zeppelins got there first.

Moving through the sea offered a way for early aeronauts to consider airspace – how to think about it, and how to attempt to master it. The construction of airspace drew heavily on the exploration of the oceans in the seventeenth and eighteenth century; not only to map and know, but a desire to master it, stripping it of its 'tempestuous determinacy'.[13]

But the air is not the sea: though it carries the forces to bounce and batter the vessels passing through it, the air is intangibly boundless, a volume without space or visible limits or definitions. Free from the concept of boundaries, it is difficult to grasp mentally.[14] Early legal debates around airspace echoed those concerning open and closed waters – *Mare Librum* and *Mare Clausum* – but concluded that it was physically and materially impossible to mark the air with a seal of authority.

While your plane moves through the sky it leaves a *wake*. When you land, you will hopefully be at an air*port* (or a *luchthaven*, or a *flughaven*) which has been designed to maximise the flow of vessels; air passengers are sometimes described as self-loading cargo. Whilst the Hindenburg disaster of 1937 was the main reason that zeppelins gave way to planes, airships were also more logistically cumbersome than aeroplanes – unable to land by themselves, they required full teams of people to winch them down from the skies onto a mooring mast. And passengers are also self-unloading cargo. As you disembark, you may catch sight of an extremely tall tower with a bulky rotunda attached to the top. A rotating restaurant for high flyers? No, this is air traffic control.

Air traffic control is not a euphemism – it is the means of controlling traffic in the air, keeping planes at a safe distance from each other and guiding them in and out of airspace. The world's first purpose-built air terminal opened for business in 1920 in Croydon, England, where employees also used a flag system to guide planes down. Radio shifted this: pilots continued to map out their own courses and were anticipated to behave sensibly as they flew. But the skies were filling up: from 1934 to 1939, the number of passengers on US domestic carriers tripled to nearly two million.[15] Planes had become nicer, fancier, with passengers experiencing the pleasures of sound-insulated cabin walls and pre-cooled and heated air. A dream of free-wheeling movement is one thing: sharing that dream with thousands of other vessels wedged into the same airspace ramped up the likelihood of collision. Controllers could give planes permission to land but offered no en route control. Near misses became commonplace. After a softly-softly approach in which airline companies promised their own voluntary arrangements on heavy routes but the skies continued to fill up, air traffic control was formalised at the national level.

The first US airway traffic control station was built in Newark, New Jersey. Reading the descriptions, you can almost smell the wood and chalk dust. In a small cabin, three controllers clustered around their tools: a blackboard, a teletype machine, a phone, and a table with a map spread out across it. It was crowded, noisy, and, befitting its underfunding, make-do; the staff were responsible for designing and making their own kit. To track aircraft, a controller would write flight information on to the blackboard, which could be revised as new reports came in. The data was transferred to the map which depicted every airway that converged onto the Newark air terminal. Each flight was represented by a small brass marker, shaped like a shrimping boat, with a paper strip attached to it. The markers were moved every fifteen minutes to estimate the real-time progress of the aircraft; and, if any airborne conflict was on the horizon, the controllers would call the airline company dispatcher to instruct the pilot to move. Each paper strip was annotated with the flight's ID number, time of departure, and altitude; near-identical details to those that my collaborator and I are summoning in from the skies some eighty years later.

The craft-based system was short-lived. In the early 1940s, under the pressure of war, the US Civil Aviation Authority assumed control of these tiny, scattered centres, centralising their work and bringing with them new

and better tech: higher frequency radio, recording devices, and – what every home needs – adjustable tetrahedrons for indicating traffic direction. The dream of a single, controllable sky moved a little closer.

Legacy is a four-letter word; that is, if you work with software. In the regular world, the technologist Ellen Ullman writes, legacy has an aura of beneficence.[16] In computing however, it is a curse; a lingering piece of junk that no one has figured out how to ditch. It must be lived with and suffered.

Air travel is peculiarly resistant to the futuristic framings that technology often suffers under, perhaps because its future-facing moment happened more than a century ago. Customer service has shifted, as the Golden Age of Flight has morphed into something more cramped and thrombosis-inducing. While military research pushes the envelope on how flight might be engineered, the shape and silhouette of commercial jets have remained roughly stable since the 1940s.

Off the top of my head, I can only think of three outliers that were put into widespread commercial use and whose differences are defined against the classic aeroplane shape: the bulbous Boeing 747; Concorde; and the full-stack widebody of the Airbus A380. Pedants may ask, what about the incredible Antonov An-225 Mriya, whose six jet engines and eighteen landing wheels give it the air of a huge and furious centipede that has somehow taken flight? And of course, there is the Airbus Beluga – a plane to carry planes, with an outsize upper carriage that gives the thing its name and an uncanny hinged forehead through which to slide in fuselages. But the Mriya and the Beluga are both cargo vessels, designed to carry freight. Commercial vessels, with their pliant self-loading cargo, abide.

The average plane is expected to be in service for thirty years before metal fatigue sets in and they are decommissioned. Like their cousins, spaceflight and military systems, the runtime for the supporting infrastructure of airspace is long; these are systems that are intended to last for decades. The old, embedded technologies are still at work, crunching away.

Old technology can be pleasingly retro or a fetish in its own right. Stripped of newness, it becomes familiar and knowable, even tame. But there is something distinctly unsettling about old code. Software, despite its longevity, always has the implication of the new. To consider old software

can feel like an oxymoron. It can exist in the shell of a machine, still pulling the levers in the background as the carapace is renewed.

Some years back, several media outlets reported that Britain's fleet of Vanguard-class nuclear submarines were running on Windows XP. The story gained traction both through the mental disconnect that something with such mechanical heft as a nuclear submarine would have a digital component, and that something with such lethal capabilities would be dependent on an obsolete operating system, whose security updates had been halted in 2014.

The sociologist Marissa Leavitt Cohn describes the difficulties of 'keeping software present' for projects which transcend the human lifespan.[17] You may have seen that photo of Margaret Hamilton in 1969, lead software engineer of the Apollo program: a young woman with long hair, standing next to a pile of paper taller than her which are the printouts for her team's flight guidance computer software that guided NASA's lunar module. The image is striking both for Hamilton's presence in a male-dominated world, and for the scale of the code on the paper punch cards. Perhaps less well known is the fact that the code was later sent to a Raytheon factory where women would weave copper wires and magnetic cores to create a rope that carried software instructions, and which compensated for the Apollo computers' limited memory.

The black-and-white photo marks a point frozen in time when technology was materially different: code is rope and software is paper. That was then. But, also, it is now. Time folds and the software persists. At NASA today, code used in some of the large-scale outer planetary science missions to Saturn (aka 'The Mission') can be more than forty years old, written in legacy programming languages such as FORTRAN. Rather than developing some entirely new system for seamless installation, engineers actively worked to maintain this ageing and obsolescent infrastructure.

This work, Cohn writes, is part technical and part social; to sustain old code, engineers must carefully patch it together with the new and know this software well enough to create a shared articulation of it (even if the software's actual documentation is wonky). Keeping legacy systems going is about working to preserve or slow the inevitable decay of diagrams, documentation, and representation. For engineers on The Mission, this involved being able to explain what this legacy code actually did, allowing

it to persist within the organisation and thus making the embedded parts of the system visible.

Engineers also created and documented the glueware of their hacks, workarounds, and scripts which allowed the old code to be gently integrated with other parts of the system. I was intrigued to see Cohn describe this as ‘dirty work’, a term more commonly used by sociologists to describe work which is stigmatised, seen as socially undesirable somehow – garbage removal, funeral direction, and sex work have all been categorised as such. Building something clean and new has the sheen of excitement; patching up a decaying, irrelevant structure while also keeping it alive in institutional memory is shittier. Legacy is a four-letter word.

So why maintain an obsolescent system at all? Well, the longer that something exists, the more embedded into the fabric of its surroundings it becomes; the more that something is used, the more people know how to use it. As NASA engineers explained to Cohn, why switch to a new programming language when they were ‘killer’ and ‘ten years deep’ in another?

In fact, new software had actually been created for The Mission as versions of existing tools in a newer programming language. But it wasn’t swapped in. Engineers, comfortable with their existing regime and having the glueware to patch over the shakier parts, rejected the new code as too ‘cookie cutter’, not specifically designed for their needs, nor allowing for care of duty or longevity.

I think about what Marissa Leavitt Cohn has to say about time when I take a trip up to the National Museum of Computing – NMOC – near the new(ish) city of Milton Keynes. The museum sits at the edge of its more famous sibling, Bletchley Park, whose beautiful buildings and low cabins have been fully preserved in aspic, recalling British codebreaking in the Second World War; it serves as a vintage amusement park/ stately home where a summer concert series plays host to swing time bands, and the corporate sponsors include Facebook and BAE Systems.

NMOC is not a beautiful building. From the outside it resembles a low-slung temporary classroom built for a term in the 1980s and then outstaying its welcome. Inside, though, instead of whiteboards and Formica-topped desks, you’ll find Colossus: the world’s first electronic computer, designed to decipher Lorenz-encrypted messages sent by German High Command.

Accompanied by a team of expert and venerable volunteers, Colossus still breathes, just about: its central processing unit runs on vacuum tubes which resemble little lightbulbs, and which aren't manufactured any more. The museum scrapes up any of these valves they can find to keep the machine going, but once they're gone, they're gone.

Software, Cohn writes, can be considered a timely object, subject to continuous change. It endures by looping into other lifetimes, entangled into the life cycles, life changes, and lived experiences of the people who work with it. To work with an older technology is to exist within the folds of time, bringing together histories and anticipated futures, working in the grey middle between how it currently performs and its inevitable decay and obsolescence.

I'm not here for Colossus, nor for any of the other small rooms crammed floor to ceiling, nose to tail, with the old technologies that unpack what 'computing' is down into process – not the glass cabinets filled with wooden slide rules and paper calculators formed of overlapping circles; nor the WITCH, the world's first digital computer which was built in 1951 to perform mathematical operations. Like Colossus, the WITCH is huge, covered in massive control panels decorated copiously with lights and switches and resembling a children's book illustration of what a supervillain's lair would look like.

Down a narrow hallway that has the feel of a secondary school in Britain circa 1988, is the exhibition on air traffic control. My collaborator and I have been thinking about the form of the work: stepping back from cultural expectations of how technologies are depicted, to consider how we want to aestheticise the movement of planes over a map. In an earlier piece, we drew on the distinctive red and black ATC system used at the now-closed Berlin Tempelhof Airport, which was, during the 1940s, one of the world's busiest airports and Europe's largest.

Airspace itself is immaterial, carved up as lines through the sky which are made present through instruments. Pilots don't determine whether they're passing through one zone or another by looking out of the window – although some landmarks on repeated routes may become familiar – but through their communication with controllers on the ground below.

Mark Vanhoenacker describes this experience of being 'seen' by air traffic control. 'Pilots prefer controllers to be watching them,' he writes. 'There is relief when controllers tell us we are "radar identified" and the

sense that we are crossing into a less isolated part of the journey.'[18] In that upper layer of airspace, where planes arrive when they reach a cruising altitude, flight planners and pilots plot a path through the available airways which can be navigated en route by waypoints and radio beacons. The latter are landbound, often in the same sites as the original light beacons.

Waypoints, though, are imaginary: a point in the air, existing simultaneously at all altitudes and defined either by their distance from a beacon or geographical co-ordinates. Each waypoint has a five-letter name, designed to be easily spelled and pronounced; very often personalised (SHARK hovers above Sydney and Maui, while pilots passing over Kansas City will encounter SPICEY and RIBBS). In place of land or celestial markers, airliners navigate by these points, while, below, ground control tracks their motion through the transponder data and radar scans.

Nearly every object which has allowed controllers to track planes in this way over the past seventy years is here at NMOC, jammed together in a tiny exhibition room. On the back wall are three large screens, emulating the view from the Heathrow control tower. To the left, IRIS – the Independent Radar Investigation System, which resembles a Dada-esque video arcade machine, with a round black convex screen set into beige plastic, and a mustard-yellow roller ball; it looks extremely satisfying to touch. And then, in a cabinet against the wall, the prize: a wooden board half-filled with plastic rectangles; the last vestiges of the paper strip system.

Attempts to overhaul air traffic control technical systems have been constantly stymied. In 1981, the Federal Aviation Administration looked to update their antiquated system, but the project stalled and was abandoned in 1994, by which time more than $2.6 billon had already been spent, the predicted costs had tripled, and the expected delivery date had slid backwards by many years.[19] In part, the failure was down to scale: the larger the project, the greater the complexity between the discrete parts and their couplings and interactions, and the more unexpected and costly *things* arise. Safety is also an issue.

Like all embedded large-scale infrastructures, it is almost impossible to take down an entire flight system in one go. The very few times in aviation history when this has happened are down to national disasters: on 11 September 2001, air traffic controllers brought every single civilian vessel in the air over the United States down to the ground, nearly 5,000 of them,

shutting down airspace. Documentary footage from this period shows a team of workers sitting shoulder-to-shoulder in front of an array of large circular and rectangular screens as they gently handle white rectangular strips of paper.

The paper in the exhibition cabinet is one of these objects: the flight strip for the last commercial Concorde flight on 24 October 2003. Concorde's supersonic speed was facilitated by its flattened delta wings and elegant pointed muzzle, but, for air traffic control, this was just one type of plane among the thousands of others, whose movements could be mapped by the information documented on the strip: departure point, route, flight level, sector, call sign, true air speed, transponder code, and vortex wake category.

From the Newark hut, paper has endured throughout decades of airspace control despite attempts to fully automate the system. In the late 1990s, Wendy Mackay and a team of fellow sociologists explored this persistence, speaking with air traffic controllers themselves and observing their workaday practices.[20] Improvements to radar, which offers a 2D-representation of aircraft moving across a predefined route, and is the backup mode of tracking should transponders fail, were relatively easily accepted by controllers. But there was fierce resistance to forced 'improvements' of the paper system.

What, controllers asked, was there to improve on? Paper worked. It was reliable. Unlike computers and radar, paper did not glitch or break down; and since controllers were responsible for people's lives, they wanted a system that worked when all other systems failed. Wendy Mackay diplomatically noted that the people handling paper could make mistakes: losing or mislaying a strip which might be swept off a table or stuffed into someone's pockets – but those types of incidences were vanishingly rare.

Paper was also personal, designed to be annotated. A scribbled arrow, pointing downwards, indicated that a flight was descending. A strip was a modifiable interface-for-one, but familiar enough to be comprehensive to others, allowing controllers to silently communicate without interrupting each other. Air traffic control is cognitively demanding work, where the bulk of information arrives and is mediated at distance by technological structures, from radio and phone contact to pilots and other controllers, to the transponder and radar data fed into screens. In this environment, flight strips formed part of a sensory array located around the controllers' bodies

which they had – ironically, given their job titles – actual control over. Paper is touchable; it enables a tactile sense-making. Controllers ran their hands over the strips to help count them, even when looking elsewhere; they could arrange the paper in such a way as to provide them with their own personal view of traffic. Even the printer that spat the strips out was part of this choreography, with its whirring noise providing a subconscious cue for controllers to prepare for the arrival of a new aircraft.

The system of air traffic control is one of distributed intelligence, where consciousness is parcelled out between ground and sky. This distribution continues within the control centre itself. As the first Newark staff worked as a collective entity, air traffic controllers moved in harmony with their surroundings, overhearing each other's phone calls and chatter, fingers touching keyboards and paper, extracting and synthesising a patchwork of information from their local environment. Perhaps most importantly, paper strips were a vital part of air traffic controllers' identity – to do away with them would damage their sense of who they were.[21]

Attempts to swap out paper entirely failed. Instead, skeuomorphs came in: electronic 'strips' which resembled their paper counterparts in terms of layout, colour, and how they're managed, though via a screen, rather than as individual physical objects. Even with shifts towards a 'stripless' environment, where information from the strips is integrated into other parts of the system, paper remains as backup if all else fails.

Paper fell out of favour elsewhere in airspace wayfinding. In the early 2000s, paper airspace charts were switched out for electronic ones which pilots could read on tablet computers. The problem here was not paper, but time: after nearly seventy years of commercial flight, mapmakers could not place all the relevant material on to them legibly, nor could pilots just select different layers of information to display or hide. The map I received from Eurocontrol is more of a legacy object than an active force, an illegible compost of the sediments of controlled airspace.

It's forty-eight hours before our exhibition is due to open. My collaborator is already in Belgium where he has spent the past day high up on the gallery roof, a space only accessible by clambering up a thin ladder bolted to the side of the building, and where he's buffeted by high winds while trying to get the antenna securely fastened and picking up enough data for our piece to actually function. It is raining in Brighton too but, knowing far less about

radio installation, I am safe indoors on the sofa, almost certainly eating biscuits and noodling online, so who's winning at art now?

When my phone rings with an unknown number I expect it to be my collaborator calling from the gallery, or perhaps our curator saying that my collaborator has fallen off the roof. Instead, I hear the terse voice of someone who identifies themselves as part of the Belgian civil service responsible for airspace management. They have seen the blurb for our work on the gallery website and are very concerned about our plans. Are we planning to hack Belgian airspace? Are we intending to send radio waves into aeroplanes travelling over the country? No, I explain, we're just picking up the signals which are already being broadcast – so, she interrupts, we're trying to intercept closed and private communication channels; no! I try to say, it's passive reception of unencrypted data through open channels, but she's already moved on. We're using Belgian airspace maps? Where did the maps come from? From you, I interject, trying to remember which specific government acronym I'd been in contact with – and then another different voice bleeds in at the edge of the conversation, though not addressing me. He's sorry, the new person says, but she can't park there as it's on the side of the highway and it's dangerous for drivers to pass stationary cars: could she please move along? The call ends abruptly; I count my blessings from the deities of infrastructural irony.

Control, not navigation, is the thread that runs through the body of airspace mapping; control which is exerted at every point between land and air – through the design of airports and the land around them, to who may willingly board planes or be boarded against their will. Aeronautical maps may indicate how pilots may pass over what is below them, but carving up the sky into discrete blocks, demarcated by immaterial geographical co-ordinates, permits nation-states to exert control over the air above them: not only to allow the safe passage of the thousands of airliners, but to determine which vessels are allowed to travel at all. A map of airspace is more concerned with where national borders lie than with mountain ranges or identifiable landmarks.

There are different textures to this control. Military no-fly zones are, as the name indicates, always out of bounds to civilian flights. The area around airports is highly controlled, to prevent interception with planes at their most vulnerable point of take-off and landing. With the emergence of consumer drones, airspace regulations had to be rapidly reconfigured to

prevent drones from being flown anywhere near aircraft, airports, and airfields. Even getting near an airport can be a challenge, with an infrastructure designed to rapidly direct that self-loading cargo in and out as quickly as possible, while actively policing its boundaries.

Gatwick Airport is the nearest to Brighton, and the one that I fly out of when I head over to Belgium the next day. Arriving as a passenger, it exerts the same forces, offering an illusion of freedom around duty free and the cafés, but actively funnelling passengers through a series of strictly enforced checkpoints. Outside is heavily controlled and monitored, filled with fencing, surveillance technology and security personnel; even the plant growth nearby is managed, as indicated by cut lawns and artificial meadows.

But the land can exert its own histories too. On foot, you can actually get surprisingly close to Gatwick's airfields. The clearly signposted public footpath which snugs around them is resentfully built, barricaded in, often including fencing running in a roof over its top. As the friend who I made this walk with described it, it feels like we are being granted access to a route which we are very much not welcome on. This is only grudging hostility: the land was here first and with it, the public right of way enshrined in England and Wales that allows us to walk through the lush green fields and forests surrounding Gatwick and seeing the planes roar into land at what feels like metres above our heads.

Control of the sky is inherited from the land. By international law, states have complete and exclusive sovereignty over the airspace above their territory, which also extends into the twelve nautical miles of territorial waters off the coastline. Fine. *How* control is exerted is a different matter. Pilots, flying along prescribed routes demarcated by waypoints and beacons, are legally obligated to follow air traffic control except in the case of an emergency, but also have final authority and responsibility for their flight. On the ground, controllers can instruct but have no direct sway over what a pilot does. It is a delicate web of response and consent which seems infallible, until it is not.

In May 2021, Ryanair Flight 4978 was travelling over Belarusian airspace en route from Athens to Vilnius, when the pilot received a message from Minsk air traffic control. 'You have a bomb on board,' came the communication. 'We recommend you to land.' A fighter jet had already scrambled to meet the flight which landed minutes later – upon which point,

local authorities boarded the plane and arrested two of the passengers, the Belarusian journalist Roman Protasevich, and his Russian girlfriend Sofia Sapega.

The event was described by Ryanair's CEO as 'state-sponsored hijacking' – but it was not. Hijacking takes place on a plane in motion, most commonly by people already on board; or, in action films, from the outside. More importantly however, the event might even have taken place without violating international law. The 1944 Chicago Convention on International Aviation is the one that assigns territorial sovereignty to the country being flown over, which includes the right to order a plane in its airspace to land, safely and without force. Nothing is there about dishonest means. The scrambled fighter jet never fired, and when interviewed by *The Atlantic*, a Belarusian representative pointed out sweetly that air traffic control had used the word 'recommend', not 'command' – the choice was the pilot's.

What this incident did, the writer Graham Wood argued, was to wholly rewrite our perceptions of flight.[22] Until this point, flying over a foreign country has felt like teleporting past it, speeding through the sealed sphere of Class A airspace. But, if the Belarus plot holds, the experience will come to resemble taking a train, with all of the terrestrial legal risk that entails.

The illegibility of my enormous Eurocontrol map is not a failure of my own powers of perception, but I don't think that it's a failure of 2D visualisations either. The system of latter-day airspace *is* horribly complicated, with plenty of gaps and nooks which facilitate the grim activities of nation-states such as Belarus legally grounding foreign aircraft, and Great Britain's increasing use of deportation flights.

Grappling with complexity only exacerbates it. If you can observe a complex system, you are already enmeshed in it. The European Union has attempted for years now to reconcile their chaotic airspace system into a 'Single European Sky', ironing away the national borders which extend up into the sky and reducing the length of flight paths and environmental costs. The intentions are good, but EU nation-states have fought back – not so much around the loss of jobs for air traffic controllers that the plan would entail, but for fear of relinquishing their sovereignty of the air.

The night that the exhibition opens, everything works perfectly – the antenna is in place, picking up the radio signals of every airliner passing over Belgian airspace and a little beyond. We've smoothed things over with the Belgian civil service; my collaborator has made it safely back from the roof to the ground.

Unpacked and processed, the transponder data is transmuted into visual forms and slung through a projector to show the planes and their information moving in real time as red trails, moving across a rotating array of airspace maps on the gallery floor. The maps are encircled by a ring of speakers, linked to the movement of the planes: as a vessel arrives, the speakers at that location will start emitting the sounds of cockpit chatter (as scraped from publicly available footage, not from the flights themselves), quieting as the plane moves away from them.

Flight unbundles time. It pries apart the cling between circadian rhythms and time zones, exposing the impassable infrastructure of uniform standard time as a human-made construct. Like the frayed sleep of shift workers, jetlag only exists because of a misalignment between someone's sleeping patterns and the patterns regarded by society as desirable. While the technologies of time discipline and orient towards specific temporalities, flight shakes out body clocks and barrels through on a mesh of old technologies and forms which stretch time beyond the human lifespan. 'We must strive, in the face of the here and now's totalising rendering of reality, to think and feel a then and there,' writes José Muñoz Esteban. 'Some will say that all we have are the pleasures of this moment, but we must never settle for that minimal transport; we must dream and enact new and better pleasures, other ways of being in the world, and ultimately new worlds.'[23]

Early in the evening, a strange man approaches me purposefully. Turns out he's my map purveyor from Eurocontrol who thought he'd swing by from Brussels after work to see what we'd been up to. I take him through the piece and my favourite part of it, the waypoints; when the authoritarian borders of airspace and no-fly zones vanish, and instead we can see our planes traversing a constellation of stars, the human-made version of the celestial navigation which pilots used to have to do over the sea. Boeing 747s used to have a sextant port as a means of taking in star sights, though now it's more likely to be used for getting fire out of a cockpit.

‘Ah’, my man says, ‘waypoints; they’ve been around a while. Do you think they need shaking up?’

4

Matter

Pier 9 juts out from the edge of San Francisco's Embarcadero waterfront, into the eastern waters of the bay. Every morning the red Bar Pilot boats dock outside its windows, through which you can see the Bay Bridge with its double stacked freeways and, in the background, the gantry cranes of the Port of Oakland. A little further to the northwest, the Bay transforms into the Pacific Ocean. Here, the water is more than one hundred metres deep in places, and humpback whales navigate under the Golden Gate Bridge.

Pier 9 is both literal and titular. The structure is an actual pier, one of dozens on the waterfront – and it is also the specific name given to the facility housed upon it. Inside this building is a state-of-the-art fabrication workshop that plays host to some of the most beautiful industrial machines one could ever hope to work on. Each contraption grapples with the physical world in some way. In the woodwork shop, a spinning table saw carves through chunks of wood like a knife through cream cheese. The next room over has a baby-blue five-axis CNC router which is an empty metal cube the size of a studio apartment. An array of sharp tool parts is strung across its ceilings and walls via a crane mechanism, allowing them to slide around in five dimensions to sculpt wood and foam into almost any shape. There are laser cutters and waterjets for slicing up metals and plastics. Almost every machine here was designed for industrial use, and word has it that this is one of the few workshops in all of San Francisco where every single piece of kit was bought new, their efficiencies undimmed by years of use.

The competence of the machines seems to meet, head-on, what the architect Bryan Boyer describes as the 'matter battle' – the power relations which matter exerts on those who would try to command it. Matter, he

writes, exhibits qualities such as heaviness, largeness, and mutual exclusivity – that is, the inability to exist in the same place as another piece of matter.[1] Unlike living biological material, matter does not have a native ability to regenerate. In this workshop, matter meets matter – metal is used to carve wood, and metal itself is sliced up on the waterjet where a directed stream of water is blasted through sand made from crushed garnet.

Matter is often missing from ideas of how systems work; or, at best, relegated to the background. It can be difficult to get a sense of bulk or weight from the pictograms and diagrams that describe what systems do, or to sense what a material substance feels like as it grinds into the behaviour of a system. In a fabrication workshop, matter is front and centre, through the materials that will be reformed and the physical machines that will do that work.

This foregrounding of matter spills into the rest of the building. The workshop sits at the end of the pier structure and to access it you have to walk through what appears at first to be standard Bay Area office theatre: sleek metal artworks in reception and a well-equipped kitchen area. Look again, though, and you will see the homespun details (if an advanced manufacturing facility can be considered ‘home’). The artworks have been made in-house in the workshop, rather than shipped in from some Cultural Capital 4 U warehouse. In the kitchen, next to the high-end coffee machine, is a bespoke metal tamper, which has a pleasing heft in the hands, for packing down espresso grounds. It, too, has been carved on the company machines. More dainty pieces of in-house art are on display on the shelves in the atrium to the workshop: fine resin sculptures as delicate as dandelion puffs and thin sheets of plywood plucked apart into a wooden *broderie anglaise*. Each piece draws attention to how working with matter can necessitate the most delicate of gestures that recognises its fragility. Behind the shelves, visible through a thick glass wall, is the waterjet; as big as the bed of a tow-truck, it’s more commonly used for cutting out aeroplane parts and turbine blades.

The workshop was designed to be a fully functional showcase, and tour parties are common: one afternoon, as colleagues and I were heaving an antagonistically large piece of steel over the bed of the waterjet, I looked up to see a crowd of people staring enthusiastically down at us from the overhead walk-way as though this was all some post-industrial Cirque de Soleil.

People are part of systems too, and people are made of matter. Fabrication facilities are very keen to emphasise this point. To cross the threshold into the workshop, you must concede that your body is soft and fallible, and that the world is ready to burn. Goggles and closed-toe shoes must be worn at all times, with ear protection and masks recommended if using the most aggressive machines. Hair must be tied back: an apocryphal story swirls round like a campfire tale of a young woman in another workshop who did not pull her long hair back into a bun and some of it got caught in a device, and her *entire skeleton was ripped out of her body.* (Not all biological matter regenerates.) What gives this story a crumb of believability is that the machines here are more than equal to this violence; blades, drillbits, jets of water that cut like a knife, electric arcs in the welding bays, and more.

I had come to Pier 9 with my collaborators Deb, Sherri, and Ingrid, for a project that explored the legacy of the Bay Area's military history on its current technology sector, through the lens of matter and manufacturing practices.[2] Predominantly contained down in the South Bay, Silicon Valley wraps itself in rhetorics of immateriality and virtuality. *Software is eating the world*, and all that – and yet, software still runs through physical machines; it is written by well-paid people who sit in buildings which are cleaned and guarded by people on far lower salaries.

The pier provides a fascinating setting to think about this tension between matter, with all of its lethal and surly and fragile behaviours, and the way that talk of systems so often pushes matter to one side. The owner and operator of this waterside industrial workshop is a software company that specialises in computer-aided design and manufacturing, or CAD/CAM. Nearly every machine here takes its orders from pieces of software. The company products are more commonly found in architectural settings where they are used to design and fabricate buildings. At the pier, we work with machines that translate a digital set of instructions into action, and we recognise that we are part of the action too.

Where does matter fit into systems? Or, to put it another way: do systems have matter? A quick read of the history of systems theorising clearly acknowledges that the physical world plays a crucial role in shaping how systems operate, from Jovian moons held in their orbit by gravitational

forces, to pilots flying their metal vessels. Matter would seem to be inescapable.

Somewhere down the line, though, matter has been downplayed and deprioritised; acknowledged to be there, but not really that important in the greater scheme of things. Digital technologies have exacerbated this framing, but this perspective is far older. Take a look at the ‘Declaration of the Independence of Cyberspace’, a speech given by John Perry Barlow to the World Economic Forum in 1996. This was the era when the new internet crawled out into the world, bringing with it the particular juxtaposition of dispersed, ‘virtual’ worlds shared through screens, and the machines that housed them.

The ‘Declaration . . .’ was written in these shifting landscapes. To the crowds at Davos, Barlow announced that the internet could not be controlled as older industries had been because it existed beyond any nation’s boundaries and controls. Furthermore, it could not be controlled because it had no materiality. The new realm of cyberspace was positioned in direct opposition to incumbent industries. ‘Governments of the industrial world, you weary giants of flesh and steel’, opens the speech. ‘Cyberspace does not lie within your borders . . . do not think you can build it as though it were a public construction project.’ Barlow berated the heads of industry as out of touch, ‘increasingly obsolete’; dim enough to think that matter was important, and that the ideas which drove the information infrastructure of the internet were ‘just another industrial product, no more noble than pig iron’. To stick the landing, Barlow forced a full split between the physical and the digital: ‘Your legal concepts of property, expansion, identity, movement, and context, do not apply to us. They are all based on matter, and there is no matter here.’

I find it really interesting that, several decades on, there is still something about virtuality which feels inherently new; just as, as Barlow implies, there is something inherently old-fashioned and staid about the material world. In the future, we will all be uploaded to the cloud, existing as pastel-coloured vibes floating through walls. Perhaps, the fact that the material world still exists keeps the promise of immaterial life alive as a tantalising possibility. ‘The central event of the twentieth century is the overthrow of matter,’ the futurist Alvin Toffler stated, with his colleagues, in 1994 – and yet, matter still abides.[3]

Truthfully, some of what Barlow outlines has come to pass – many Big Tech companies have shown themselves to be more powerful and more difficult to control than any individual nation-state. Yet what should give us pause is the knowledge that the ideas at the heart of the Declaration are actually very old too. You can map a direct line between its arguments, and the emphasis in cybernetics on information over matter; and, even further back, to the uncoupling of the idea of 'system' from a specific context. The philosopher N. Kathryn Hales has traced how embodiment was systematically downplayed throughout cybernetic theory, from the initial conceptualisation of humans as information processing entities, through to the later development of 'artificially intelligent' creations deemed to be 'life forms' because they were composed of informational code.[4]

There is brilliant and necessary work from artists, activists, and scholars who draw attention to both the very physical things that allow technological systems to operate – data centres, server farms – and their material effects, such as environmental pollution.[5] This work is ongoing because it can still feel as though these elements are secondary to the main idea of 'technology' as a dematerialised thing: the ghost, not the machine. Everyone knows that the physical world exists, but the direction of travel is steered by rhetoric that it does not. And this is where the politics of technology gets messy.

I arrived in San Francisco in early 2016, in what proved to be an auspicious season for matter. Down the road in Palo Alto, the biotech company/grift extraordinaire Theranos was about to come under criminal investigation for allegedly misleading investors and the government about its technology; that is, for pretending that its small Edison machine could reliably extract vast quantities of data from minute volumes of blood. None of it worked; when potential investors visited the facilities, the blood samples were spirited out of the devices and snuck into labs elsewhere in the building which had the full complement of equipment necessary to run the tests. Here, at least, truculent matter and the physical laws of the universe dominated over informational patterns. For now, though, that's all happening in the South Bay, out of sight, apart from the odd conversation with hardware engineer friends who had heard rumours drifting through their professional networks and wondered, how exactly do the Theranos machines work?

Up at the pier, there's no mystery about how the workshop machines work. The idea of immaterial systems may be old, but the 'weary giants' of architecture and construction are around today and grappling with software and other digital systems that we plug into the machines here. More than that, in fact, architecture has shaped our common understanding of what digital systems are. The term 'information architecture', which describes a shared digital environment, is not simply a metaphor but an acknowledgement that these systems were first built for architects who had turned to computers in the 1960s to try to meet the growing complexity of their profession. They, in turn, often worked with cybernetic theory to try to visualise flow and feedback in design problems.[6]

In systems design today, architecture is a powerful metaphor that engineers and designers use when they want to talk about complexity because an architectural problem *is* complex, with three-dimensional elements and real-world qualities of scale and matter.[7]

In short: it is because of – and not despite – their physical endpoints that architecture and its constructs are neck-deep in software. Perhaps the most widespread of these digital objects are computer-generated images. They are pervasive, influencing what the places we live in and the technologies we use look like, and how they function; yet they do so in ways which are so inconspicuous as to appear mundane and acceptable.[8] Companies like Theranos frequently produce realistic digital images of what their devices will look like for a pitch deck to investors, independent of what the company engineers are attempting to build.[9] Digital renders in architecture are commonplace for the same reason: to make a sell on what a building might look like before the first brick has been laid. Look at the images on any architectural hoarding of a gleaming building backed by blue skies and clean roads and feel the dissonance between what's on the board and the swarm of the construction site and the very real, very chaotic urban landscape beyond it. As the digital theorist Joel McKim explains, these architectural renders are not meant to capture reality as it is, but instead bring about a certain reality through 'urban speculation'. The photorealistic images created for promotional materials 'signal the inevitability of this process before it has even begun'.[10]

No matter how pretty the images, sometimes, though, matter can resist. My favourite example of this comes from the mid-2000s when the British

government tried to rebrand a chunk of East London as ‘Silicon Roundabout’, to attract foreign investment. As part of the scheme, the then and future prime ministers David Cameron and Boris Johnson dreamed up a multi-storey, architecturally iconic building intended as equal parts tech incubator and spectacle. For publicity, they commissioned a digital render of the structure sitting atop the roundabout at Old Street underground station. Industry press dubbed it ‘The £50m Thing’. Architects pointed out that, despite what the digital image depicted, the building was physically impossible to create: had it been built, it would have placed too much weight on the station and crashed down through the earth. The Thing never materialised.[11]

Despite attempts by British politicians to pretend that gravitational forces do not exist, matter can exert its will over its digital counterpart – but somehow, is still seen as its inferior. The digital media scholar Jacob Gaboury points out that computer graphics saturate the world as we know it, and yet coyly draw a curtain over just how they were made and how they function.[12] They also draw a curtain over what they contain. In architecture, Business Information Modelling (BIM) software programs are embedded with huge amounts of data which allows architects to create ‘intelligent objects’ that contain information about themselves, such as their material qualities.

Architecture is not the only place where these types of objects are made. Entities in a Pixar movie do not float but, if played for realism, move in a way which is commensurate with their specific material qualities, and the gravitational forces of whichever world the story is set. Dropped from a height, a digital rubber ball will bounce.

At Pier 9, the rubber ball meets the road. Digital fabrication closes the gap between material and virtual worlds and mushes their faces against each other. The term covers lots of different processes, but very broadly: in digital fabrication, a computer program is used to create a model of something in two or three dimensions. A different piece of software is then used to generate the instructions for the machine to make this model, as a series of choreographed steps. These instructions are then fed into the machine itself which uses physical tools to recreate the model out of some material. A ‘subtractive’ process, like laser cutting, will make the model by carving into materials; an ‘additive’ process, such as so-called ‘3D printing’, will take materials such as resin, clay, or even molten metal, and

deposit layers of it to create a specific three-dimensional form. The sculptures in the workshop's antechamber have all been made in these ways. Whether etched with a stream of plasma or built up from fine layers of resin cured with ultraviolet light, the common ancestor for each is a digital model.

For most of the time, digital images are the endgame, meant to be experienced from screens and hoardings. The material parts of the process are kept hidden away. But in fabrication workshops, digital models are squished into the middle of the workflow, no longer an endpoint in themselves but a message to be given to another machine to manifest physically. In the workshop we called this moment the handshake, like some shady backroom deal where, over a stiff drink, a computer graphics engine and a 3D printer agree on the job to be done. And this is a great place for thinking about how matter matters, and of the wrestling match between physical and digital forms; and what happens when the cultural associations around virtuality and systems meet a plasma cutter that has caught fire for the third time that day.

One of the first things I do at the pier's workshop is draw a line – not just any line, but one which the machines here will recognise. To begin, load up a vector graphics program on your computer. Adobe Illustrator is popular but there are many others. Place your hand on the computer mouse or stylus. Click somewhere on the blank screen. Move your hand, and thus the cursor in the direction and length that you desire and click again: a line is formed. These two points are the anchors, and the line is the path. If you now give a file of this image to a laser cutter, it will translate the information into a series of instructions which guides the laser in a specific direction, for a specific distance. The line becomes the cut.

If you have used these types of programs before then this description might read as painfully overcomplicated, like telling someone how to walk with one foot in front of the other. Words don't easily describe what the body does. But using a computer graphics program does mean using your body in a way which becomes extremely clear if you want to turn your line into a curve. So, in your software package, you'll find a curvature tool which implies that this transformation will be easy. Using this tool create a new line from two more anchors and a path, but now move the cursor around and the line will flex and convulse. Click again and the line will be

fixed into a curve. You can add more anchors if you want to make more flexes and, eventually, you'll have the undulating thing you desire.

If this sounds easy, it absolutely is not. The line will sassily spasm under your cursor, bending and bouncing like it's at the club. It is frustrating and enraging. Much of my first few hours getting to grips with vector graphics involved clenching the mouse and hissing at the screen 'You . . . you *prick*'.

Once we calm down again, this experience shows us two important things. First, digital fabrication involves physical work. Computerisation has ostensibly made the process of graphic drawing and analysis far less onerous for designers and architects – a 2D drawing can be more easily transformed into a 3D model, which in turn can have adjustments made to it as the work progresses. But at the end of the day, someone still has to sit down in front of a screen with a mouse or a stylus and swear. This type of work is often tedious and repetitive, as exemplified by the terms 'CAD monkeys' and 'BIMpanzees' – terms used in the architecture trade to describe rote roles requiring little creativity or agency. To use the phrase in context, see the architecture student who asks on Reddit, of being offered a job as a technician in an engineering firm, 'no design input, no creative development; just being a CAD monkey. Should I take the job and enjoy the monetary benefits and its tenuous link with building design?'

The second important point is that a technical model is built into CAD that limits what the program can do, and these limits are predetermined by human choices. The curves in nearly all graphics programs are based on 'Bézier curves', which mathematically model the curve of smooth objects. You can bake anything you want into a software program, but if you are using it to make something that stands up in the physical world you probably want to bind it to physical forces. Bézier curves began life as splines: long thin strips of wood which could be anchored in places at different points, and then bent into the desired shape with weights. Naval architects used splines to standardise irregular curvature in their drafts, repeatedly bending and fixing them to produce the exact same shape across different drafts. In the 1960s, the automotive engineer Pierre Bézier created a digital version of splines for the UNISURF program for car design, and that's what we still have today. Part of the frustration of grappling with curvature in CAD is the disconnect between the tensile force modelled into the digital object with the experience of how this translates into

manoeuvring a mouse or stylus; a mathematically generated twin which demands physical subservience to its own logics.

Together, these elements show us that materiality has been a constant part of computer aided design. But they don't tell us how it got there, or why. To do that, let's take a look again at our CAD monkey and ask why that crappy job exists for someone who has years of expensive and challenging architecture education under their belt. It sets up the question: who designs and who materialises? Who creates and who makes? And if they're not the same person – why not?

Throughout its history, the field of architecture has created a divide between what is represented and what is built, and between the mental and physical activities required for both.[13] At work, this played out as a split between the people who applied intellectual expertise to master materials, explore their plasticity, and define what they could do and the people who directly engaged with materials to fix them into place. The design scholar Daniel Cardoso Llach explains how architects created a powerful managerial role for themselves which allowed them to oversee the process of creation and construction, but left it to the builders to get their hands dirty.[14] Educational training programs set up in North America during the nineteenth century cemented (sorry) the split, providing alumni with the credentials to scaffold (sorry) a high-status professional identity that differentiated them from mere tradesmen. With this, architects had begun to build themselves a staircase to the higher echelons of the class structure, designing in a power asymmetry which they benefited from. And who, from the top, wants to descend into the dull, dangerous, and poorly paid drudgery of labour on the building site?

Drafting – the creation of drawings which represent a structure – is an intrinsic part of architectural practice but doesn't easily fit into the binary above. Unlike the heavy construction work involved in making a building, bridge, or boat, drafting contains little muck or risk. Taking place away from the building site, drafting demands skill with paper and pencils. It could be thought of as a refined activity, maybe even artistic, were it not for the fact that the purpose of the work is to translate an architect's intention, not to create something new. New rhetorical devices further separated architects from their physical labour. To 'design' became a creative endeavour, while 'drafting' was its mechanical and technical realisation.

The work of drafters had value only inasmuch as they represented architectural purpose; without this, those drawings were only ‘dirty marks on paper’, closer to the construction site than the studio.[15]

These power dynamics played out in architecture’s managerial structures. As Llach explains: ‘The ideological construction of the architect as a gentleman, a scholar, and artist, mostly unconcerned with materials and labour . . . plays against the struggle to re-establish disciplinary authority over building production.’[16] And this was the context that design technologies landed into.

As we’ve seen, machines running on CAD are commonplace in automotive and aeronautical engineering – for creating the curves on cars or cutting out aeroplane parts. By comparison, architecture was slower in adopting CAD; without industrial economies of scale or military support, architecture firms couldn’t afford the expensive kit necessary to run graphics programs. But, cost aside, the prospect of using digital technology to solve architectural problems was appealing.

Llach describes how the architect Frank Gehry advocated that, to prevent architects from being ‘infantilised’ by the ‘parental’ contractor, they should be placed at the very top of the process of design and construction, allowing them to supervise and control all trades with minimal friction.[17] Computer modelling programs, such as Gehry’s own ‘Digital Project’, which created 3D interactive interfaces, could enable this process by splitting the architectural workflow into two stages. In the first, the ‘creative’ stage, architects come up with their ideas, which are then plugged into a machine for the second, automated ‘mechanical’ stage.

In short: the power dynamics set up between architect, drafters, and builder were now reproduced into CAD. The dynamic plays out, very lightly, when I create a line to be laser cut, though for true industrial authenticity I would need to pay someone else, poorly, to draw the line in Illustrator that I’ve imagined.

But maybe your attention, like mine, snagged on the word ‘infantilised’. If we have learned anything about human-made systems so far, it’s that they have human intent designed into them. The intent of CAD is to further separate the architect from their labour and elevate them above those who carry out the dirty work. To paraphrase *Mean Girls*, when did it become okay for architects to be the boss of everybody?

For Gehry this entitlement came from patriarchal authority – if an architect was marginalised, he was feminised, ‘treated like women are treated’. But a CAD program like Digital Project ‘turns the feminised artist into a man (a father) again’, re-virilising him. Other men could do the grunt work of building – construction, too, is a male-dominated sector from top to steelcap toe – but architects were to be transformed into a special man, a *starchitect*, with power over labour and materials.[18]

These baked-in power dynamics persist today. If architects once dictated the material form of a building through their ideas which were codified into technical drawings and models, CAD fixed these ideas further. A pencil line can be erased and redrawn but a line in CAD can only exist within the presets of the program, collapsing the creative and mechanical stages into lockstep. We may think that we’re merrily drawing lines out of our own free will to pass on to subservient machines, but our imagination is ultimately constrained by the software designers.

In fairness, as CAD emerged into the world, the power dynamic between architects and their machines did not go unchecked. What if this relationship could be less hierarchical, and instead something more egalitarian and collaborative? These questions underpinned the formation, in 1967, of the Architecture Machine Group – AMG – which was housed at MIT and brought together architecture, engineering and computing to challenge what architecture might look like. One of the founders, Nicholas Negroponte, envisioned a new ‘architecture machine’ in which design processes were closer to conversation than instruction, ultimately creating a symbiotic relationship between people and machine.

To be clear, AMG did not work with CAD software or rendering programs which had a physical endpoint. Instead, as the design scholar Molly Wright Steenson describes, the group tried to reimagine what a computer could *be* in an architectural setting.[19] Rather than creating tools that could be used to design buildings, AMG explored what machines themselves could learn from architectural practice. Just as architects learned through embodied action, so too could machines. The idea resonated with earlier cybernetic concepts that likened a mechanical system to a biological one. ‘Does a machine have to possess a body like my own and experience behaviours like my own in order to share what we call intelligent behaviour?’ asked Negroponte.[20] (Hold on to that ‘like my own’ – we’ll

come back to it shortly.) Audio and visual sensors helped machines to become sensory, but so did people.

The Media Room lay at the heart of AMG's operations and embodied its intent. It, too, was figurative and literal: an actual room, covered floor to ceiling on three sides by thick dark fabric to render it soundproof. A huge screen was built into the fourth wall; opposite it, in the centre of the room was a chair with touchpad joysticks built into it and smaller touchscreens within reaching distance. Here, the user was designed into the action. As they sank into the chair, they became at one with the machine and became enmeshed into a whole system of computational action that combined the user, the interface, and the environment together, seemingly without hierarchy. There wasn't a 'computer' in the Media Room – everything in the Media Room *was* the computer.

The embodied action of working on a computer graphics program was the very point of the research group, where the movements and expressions of the user were translated into command. Take *Put That There*, a project which explored voice and gesture recognition. A video of the project from 1979 shows a blond man in a red jumper sitting low in the control chair. A huge black screen fills the wall opposite him. He moves his left wrist: a white cursor appears. He points to the upper right of the screen. 'Create a yellow circle, there', he instructs, and a yellow circle appears. He gestures and instructs again, and a blue triangle appears on the lower left. The assemblage recognises both voice and movement, accurately interpreting 'put that there' and 'move that below that'. Everything goes swimmingly until the demand to 'create a large green circle, there'. A red circle appears. 'Ah . . . shit' mutters our man, shaking his head. 'Restart.'

In theory, what was being built by AMG was far more egalitarian than the longstanding power dynamics that privileged architects over drafters and builders. Certainly, the environment was more comfortable than most architectural studios today and the kit was state of the art. But was this truly a more democratised process of design? That's more of a stretch. The people using the system may have been the same people who designed it, but they were all part of the same exclusive research community in the elite space of Cambridge, Massachusetts, drawing prestige from their academic home at MIT, and milking government defence departments for hefty rolling research contracts. This work was a long way away from the daily grind of CAD monkeying.

To get a sense of whose bodies were valued in the Media Room, let's return again to Nicholas Negroponte's comment of 'a body like my own'. This phrasing is telling – whether consciously or not, Negroponte is not referring to a body which, like his, is human, but to a body belonging to someone equally privileged and valued. Our first tell for this are the AMG projects – ostensibly blue-skies research, but actually seeding applied military work. In the first iteration of *Put That There*, abstract brightly coloured geometrical shapes floated across the screen. Four years down the line and the squares and circles had been replaced by oil tankers and submarines, floating over a map of the Caribbean, with the man in the chair gesturing towards Havana and the Dominican Republic. What began as abstract research into gestural interfaces ended as military command and control.

This is the precursor to drone warfare, where operators were physically distanced and protected from battlefield destruction in places far from American soil. 'Detached but connected' is how Steenson describes it as project after project rolled out of the lab, ostensibly exploring new ways to work with the spatial aspects of architecture but steered towards military use which reduced the death count of US soldiers while amping up devastation elsewhere.[21]

The second point of privilege came around the chair in the Media Room. It was not just a spare chair, dragged in from another room on campus. This was an Eames Lounge Chair, chosen specifically by the group. The Eames is a delight of a chair, designed to emulate old English club furniture. Slung low and upholstered in leather, it is a chair to relax in. Early schematics of the Media Room show an unremarkable 'Users' Chair' linked up to the screens and machines, but as the room went into development, MIT researchers deliberately selected the Eames to elevate the status of people in the room. Status and comfort are linked: those with elite identities will have their bodies treated tenderly in the workplace and elsewhere; everyone else can suck it up with computer vision syndrome and repetitive strain injury.

AMG's work was instrumental in scaffolding specific sensibilities around architecture into the emerging landscape of digital forms, introducing the idea of 'information architecture' as a way of understanding and building interfaces and digital systems. Rather than challenging what architecture was and the power dynamics embedded into it, AMG replicated

and extrapolated those dynamics into a new environment. Years down the line, the ideas fomented at AMG diffused out into the wild, with ideas around information architectures and human-computer interactions now commonplace today. But the user was no longer in a privileged position but right back where they started, except now putting more of their body to use. The Eames chair stayed where it was, back in Cambridge.

One of the criticisms levelled at AMG was that their projects were all mouth, no trousers – showpieces designed to attract attention with just enough realism to ground the theatrics.[22] Like architectural renders, AMG were more spectacle than verisimilitude, something that intentionally separated a concept from the political and material reality that it would later find a home in. When AMG transformed into MIT Media Lab in 1985, their abstract and playful projects provided a natural throughline between the old group's emphasis on architectural affordances and the new focus on media systems. But I think this spectacle also served an additional purpose here in continuing to sever the ideas of architectural work from the material reality of what gets built, and how that construction happens.

Several weeks into my time at the workshop and the interplay of bodies and matter is very much on my mind, and specifically, my eyes. When the skin starts peeling off my eyelids, my first thought is of severe hay fever from the foreign Californian springtime blooms. It takes several rounds of antihistamines before I clock that this is more likely to be an allergic reaction from the resin residue wafting off scores of printed objects; barely even dust, but enough to make me look like a weeping naked mole-rat.

There's a lot of dust. The hype around digital fabrication is very clean: finished objects which exactly mirror their render, where the only way to tell the difference is how the light falls on each. The process of fabrication makes itself known, though. There's a miasma of hot particulate in the rooms, and the scent of burning wood rising from the laser cutters, which I really like. I make a series of plywood sculptures with as many lines and curls cut into them as possible, all the best to huff their burnt smell afterwards.

A book gets passed around my friends which helps us make sense of the sensory nature of the place – not the official workshop handbook, but a copy of William Gibson's science-fiction novel *The Peripheral.* Gibson is superb at crafting the feel of different places and spaces, moving past just

introducing Weird Sci-Fi Stuff to explore how this stuff exists in the world. In short, he's a writer with an acute sense of systematicity. How are these things legislated? What do they feel like? What do they *smell* like?

The Peripheral was published in 2014, at a point when digital fabrication was starting to infiltrate mainstream consciousness. Set across several near-futures, one of the story's protagonists is Flynne Fisher, a young woman who works in a small 3D-print shop in rural America. In this world 3D printing is cheap and plentiful; cars can be printed to order and smell of 'freshly printed electronics which, like a new phone, will wear off in a few hours'.[23] Illicit printing – guns, drugs, invisibility suits – carries hard jail time, but smaller shops like Flynne's are willing to do it.

But what I really and self-indulgently loved was Gibson's quotidian description of a working day at the shop because it was so similar to my own. Flynne arrives at work:

> Locked her bike in the alley and used her phone to let herself into the back of Forever Fab, smelling pancakes and the shrimp rice bowl special from Sushi Barn. Pancakes meant they were printing with that plastic you could compost. Shrimp special was Shaylene's midnight snack.
>
> Edward was on a stool in the middle of the room, monitoring. He wore sunglasses against the flashes of UV, with his Viz behind the glasses on one side. In the low light, the glasses looked the same color as his face, but shinier . . .
>
> She glanced at the long worktable needing the removal of afterbirth, smoothing, assembly. She'd spent a lot of hours at that table . . . looks like they were printing toys tonight, or maybe decorations for the Fourth.[24]

Gibson is sensitive to the material economies of his world. Flynne's down-at-heel life is filled with things that have been bought online and then repurposed, patched together to make them fit for function. This extends to the materials of the prints: just as my colleagues and I cost up the resins we work with, Flynne notices that a new and illegally made object would be indistinguishable from its industrial counterpart, had it not been manufactured out of 'sugarplum fairy stuff'.[25]

But I think what Gibson best captures about this near-future work and the weird slippage between digital model-to-physical thing is in that incantation of 'removal of afterbirth, smoothing, assembly'. The hype around digital fabrication presents a seamlessly clean process whereby people in pristine clothing neatly pluck perfectly finished objects out of the machines. As we've seen, the reality is far messier because fabrication

involves working with matter; but there are also certain things made out of matter which only emerge because they are part of a digitally driven process.

Afterbirth is everywhere in the workshop. The printer that I make the most use of – a Stratsys Objet 500 – builds its objects out of layers of fine resin which are cured with UV light throughout the process. Building with what is functionally microscopic droplets of ink allows the machine to create incredibly delicate pieces. In the final part of the build, the object is bound in a protective transparent blueish gel caul which makes it look like a ghost Jedi. This coating is a necessary endpoint to using digital tools that permit such delicate things to be made, but also requires them to be intact when they come out of the machine. I spend hours at a workbench, far longer than the print itself took to complete, carefully removing the caul using an array of sharpened metal sticks which I later find out are actual dentistry tools. ‘Smoothing and assembly’ are part of the process too – rather than being printed as finished and complete, digitally fabricated objects are often printed in parts, connected by bridges which need to be filed off when they come out of the machine. There’s a whole array of careful manual work which needs to be done at the end of a 3D print to make the thing resemble its original digital model.

We can see the physical imprint of digital models at the architectural scale too, to the extent that those who know their digital tools can identify the presence of a particular software package in the shape of a building, through its curves and forms.[26] As architectural building programs improve on themselves, the buildings change too – not because of any shift in the material qualities of, say, concrete, but on what the software can demand of the builder and the built environment.

For example, I spent an extremely pleasant afternoon chatting with my friend Alex Leitch, a creative technologist, talking about the peculiar structure that is the Mississauga Civic Centre. To the untrained eye, the complex appears to have been flung together from an array of Duplo blocks: at the back, two cuboids, one squat and one tall, and a cylinder, and out front, a massive ‘house’ shape of a rectangle topped by a triangle. The architects responsible describe how their design followed a structured classical plan, inspired by the farmhouses, silos and barns of local Ontario. And yet, as Leitch points out, to the modern eye it appears to have been designed using early architectural software programs. ‘All of the buildings

are made of a style of platonic solid that comes free with purchase in 3D software,' they explained. 'They're shapes that are awkward for humans to draw, but easy for computers.' Across the structures, all the walls and windows and atrium halls are strangely 'snapped to edge' – that is, lined up with everything else, and which is a setting in older default AutoCAD packages.

Most of all though, the scale of the structure is off. At first glance, the simple geometries of the structure make it hard to get purchase on how big it is and it's only by looking at the tiny cars in the nearby parking lot that shift everything into focus. The building is too big for what it is. 'The scale is exactly wrong for an impressive building built with human measurements,' says Leitch. 'It's just too big in that weird way which happens when people draft something without thinking what it'll be like to actually walk around it. It's all proportionate but only to itself, which is a hallmark of scale errors in CAD projects, the type of thing that happens when people haven't had much experience with translating from screen to in-person.'

Leitch and I agree that it is our uncertainty around how to comprehend the building that makes it truly unsettling. The winning pitch for the Centre was picked in 1982, the same year that AutoCAD was released. It exists in the liminal space between being composed of the architectural shapes which inspire software, and being an architectural structure defined by software, and it is difficult to determine which way the polarities flow. A photograph of a white scale model of the building produced by the architects is completely indistinguishable from a 3D CAD sketch.

In short, a building like the Mississauga Civic Centre exemplifies the shifting relation between representation and reality, in which digital information is closely coupled with the material logics of construction.[27] This intertwined aesthetic and build indicate something crucial about the use of architectural software as a definitive tool: though it might seem like a neat step to slot into the design process, it brings something new with it, like characters in Stephen King novels who return from the dead, changed; something which someone, somewhere, has to build and live with.

The discipline of architecture has played a neat three-card trick, enabling senior architects to place themselves in a position of control over the process of creation and production; absorb the wealth and status that came from being in a managerial position, and the kudos from being a

‘creative’ type in black polo-necks. Most of all, they have created a story about how absolutely normal all of this is. And so: if digital tools both change the aesthetics and exacerbate the power dynamics in rendering creative thought into material form, what does this look like for those that must actually do the manual work at the bidding of the digital model? Where are the builders in all of this?

Let’s return again to the matter battle. Working with matter is difficult because of how it behaves and requires a specific sensitivity which attends to and willingly understands its complexity. As N. Kathryn Hales says, ‘Anyone who actually works with embodied forms, from the relatively simple architecture of robots to the vastly more complicated workings of the human neural system knows that it is by no means trivial to deal with the resistant materialities of embodiment.’[28]

To deal with something may also mean giving oneself up to it. The most nerve-wracking moment in digital fabrication comes in the handshake when you cede control to a physical machine, powered by electricity, spewing out matter. Once a digital file goes to print, all you can do is wait. 3D printing is slow and it’s common to run big print jobs overnight. It’s only on returning to the workshop and lifting the lid on the printer that you find out whether or not the print worked. Almost all of the time, the process works as it should and all that needs to be done is the filing and smoothing. Sometimes, though, things fuck up. Filament gets stuck and builds over itself, accruing in a way that wasn’t in the original plan, forming grotesque gaps and bulbous outcroppings. A power glitch might jar the workflow. In theory, CAD/CAM software weeds out all the ways in which a digital construct might be impossible to build in the physical world, analysing and picking up the ‘clashes’ where certain pixels should not be. But in practice, once the machine starts chugging away on the print, that’s it – the laws of physical behaviour have primacy.

On a construction site, things work differently. Digital models are used to define the form of what is being built, but the build is carried out by people. Architecture scholars have admitted to getting stuck in imagining whose work matters the most. Peggy Deamer talks of being challenged when considering whose contribution to her house renovation was more important: the plasterer with ‘his material labour of construction, or our immaterial labour of thinking, drawing, and model-making. Who

determines the design of something – the fabricators or the architect?'[29] On site, though, the fabricators make their own interventions, through their own material labour and – yes – thinking. It's common for changes to be made during construction because of circumstances that only emerge on site, whether relatively minor or very significant. As a result, clients often require an 'as-built' drawing: a legally required document which corrects the original plans to indicate any changes made during the build phase. There will always be differences between what is designed and what is built.

In practice, then, virtual software on site is mostly applied to discipline labour: to surveil construction and identify where workers are being unproductive, either through their own human fallibility, or through planning inefficiencies.

Yet the disciplinary bind of software threads throughout the chain of design and construction. As we've seen: architectural rendering programs have their own aesthetic and structural biases baked into them, which influences the design and form of the built environment – but also limits the architect in terms of what they can imagine and create.[30] Scaled out and down into drafting, we see how imagination and creativity are also shut down by mainstream BIM programs for the lower-waged architectural workers, whose days are spent inputting data and fixing bugs. Matter might be the endpoint for construction and architecture, but, Amelyn Ng argues, it is BIM software which is the de facto industrial medium of these industries, ushering in efficiencies and optimisation by synchronising building information, reducing labour costs; and, with it, limiting imagination, costing out ad-hoc problem solving, and locking matter into the unforgiving fixity of proprietary software.[31]

And yet, matter *is* the endpoint. Even if, as the architect writer Tamar Shafrir argues, architectural education has sacrificed proficiency with building materials for privileging the functionality of software packages and creating forms of human labour which are more machinic – even then, matter will still exist, beyond software. Even when software is tasked with defining and controlling matter, matter can bite back.[32]

So, what does the matter battle look like in the light of a software-defined process? How can one execute the desires of the mind into physical

matter if a proprietary software program has the entire proceedings in a headlock?

The architecture scholar Megha Chand-Inglis argues that the conventional distinctions between manual and digital practices are insufficient to understand the messy nature of present-day architectural work.[33] She offers up a factory in the city of Ahmedabad, as an example which in 1997 undertook its first CAD-CAM enabled architecture project. The building in question was a Shree Krishna temple in West Bromwich, a town in the centre of England. The temple was to be filled with ornate sculpture and fittings, with the design and construction process driven through three people: a temple architect (who was also a civil engineer), a clay modeller, and a software engineer. For all of them, the software and hardware on offer to fulfil traditional architectural CAD work wasn't fit for purpose, having been designed for situations which had probably never conceived of Hindu temples or the delicate and complex carvings within them. As a result, each of the three had to substantially adapt their practices and find workarounds to get the job done.

For the temple architect, who worked in a long lineage of sculptors and restorers, the challenges began with the CAD presets. With a lack of suitable inputs in the off-the-shelf CAD programs, temple architects went through their libraries and scanned in free-line drawings created from generations of temple design into AutoCAD, to be used in creating digital models. And remember the problems with not realising the scale of things built in CAD? Temple architects in Ahmedabad got around that by printing out full-size images of their digital designs, and then laying them on the floor to judge the scale of what they were making against the size of their own bodies.

Alongside the temple architect, a clay modeller designed statues for the temple. Once again, existing software was not up to the task. The 3D shapes of the sculptures were too complex to be drawn in AutoCAD, so the modeller made them up in clay and then scanned them with a 3D scanner. The resulting digital file could be fed into a CNC machine which would carve the figures out of stone. Even then, there was a gap between the desired shape of the clay model – whose form was assessed by both sight and touch, as the clay modeller ran his hands across it to assess its perfection – and the manifestation which emerged from the CNC machines, defined by a numerical language and requiring a human hand to bring it in

line with what the clay modeller envisioned. Foreshadowing our experience in the workshop, these statues needed be polished by hand to remove the ridges left by the machine before final details were added by stone carvers.

Finally, the software engineer was the one who had to stretch the capacity of these CNC machines far beyond their first purpose. Originally designed for milling bathroom and kitchen worktops, the machines had limited rotation around their axes, which meant that the engineer had to manually rotate the objects in them during the carving process. The software that came with the CNC machines also needed adjusting as it wasn't compatible with the type of three-dimensional forms which the sculptures embodied, meaning that the software engineer had to write his own programs in order to generate the machine commands necessary for making the architectural forms suitable for the temple.

Together, as Chand-Inglis describes, the highly skilled work that these three people do challenges the idea of software as supreme instructor. 'Instead of making traditionally trained labour redundant,' she writes, 'the production process relies heavily on these very methods of sculpture, masonry, and drawing, to provide data for fabrication and for the finishing stages of the CNC milled stone.' It would be comforting to offer up this story of the West Bromwich Shree Krishna temple as a way of escaping software's role in limiting imagination and disciplining labour, but I think it works better as a cautionary tale about the possible unchecked endpoint of a world defined by the inbuilt aesthetic and political systems of CAD. First, the difficulties experienced by each worker at every step of the process highlights that creative expression through these machines and models is flattened into one with its roots in US militarism. The manufacturers of the CNC machines were no use; they 'did not know about Indian art and had no idea that this work could be achieved by their own machines'.[34]

And this brings us to our next point, which is the ubiquity of these programs. The team behind the Shree Krishna temple were lucky, in a way, that they were all on the same page in terms of what they wanted to build and how they needed to subvert software and CNC machines to achieve it. Much architectural practice today is maybe, actually, closer to John Perry Barlow's accusation of weary industry giants building yet another construction project, but now with all parties involved using the same version of the same BIM package. When the only tool you have is a hammer, it is tempting to treat everything as a nail. When the only tool that

every architectural worker has is the same proprietary, mass-market software, it is tempting to treat the physical world as a manifestation of the parameters set up by the code. Pushing back on the immanence of this situation is the real matter battle.

The day before I am due to use the plasma cutter at the workshop, I go back through my email and dig out the original legal contract that I signed in order to work here. I have worked on machines that are technically far more aggressive and dangerous, such as the table saw and the waterjet. But the plasma cutter, which uses targeted fire to slice up metal, has a terrifying chaotic-neutral energy all its own, and I worry whether this will finally be the day that I set my face on fire.

The contract was as hefty as these types of legal documents are, dozens of pages long and a pain to sift through manually. A keyword search for ‘bodily injury’ pulls up detail of personal liability. Search for ‘harm’ though, and a section on malware pops up together with a legally binding promise not to use viruses, Trojan horses, spyware, or any activity which might damage the operations of a computer system as part of the work – work which is referenced some pages later as a ‘physical manifestation’. It seems that a legal and financial perspective is quite capable of considering matter and software as equal parts of a complex system, inasmuch as both elements can contribute to the workshop owners being heavily sued for damages. Turns out that the possibility of a God-scale financial loss is very good for clarifying the mind.

N. Kathryn Hales argues that an abstract pattern can never embody actuality.[35] I wonder, though, whether this is really the question at hand. Those with power don’t necessarily care how material instantiation is achieved, only that it is, or appears to be in a way in which no one at the top loses their status. Imposing the power dynamic is the point. Hales cites the feminist sociology scholar Dorothy Smith, who reminds us that men of a certain class are prone to decontextualisation and reification because they are in a position to command the labour of others.[36] Reducing the complex embodied nuanced essence of flesh and steel down to a simplified and transferable motif is also part of this process. Who, from the top, has the time or will to deal with the mess of the world? Let the little people handle it. The ‘architect of the future’ is often depicted as a smartly dressed man strapped into a VR headset, staring into a digital model of how the site will

look when it’s all done, rather than at the people pouring concrete and levelling planes.

But the digital realm is needy. Not only does it require its own flesh and steel – people to program it into existence, electricity and machines to live through – but it also makes its own demands on that flesh and steel as its patterns move into the physical world. Pushing back on these demands requires marshalling matter right back again.

In the workshop, I load my designs into the machine, clamp the metal on the cutting bed and then set my zero value – the point where the x and y axes will meet. When the plasma cutter is fully equipped and ready to roll, my instructor hands me a spray bottle filled with water. ‘For when it catches fire,’ he says. ‘If . . . ?’ I ask. ‘When,’ he says firmly. I press start. The hot beam of transient fire hits the sheet of steel and the residual scraps of matter in the bottom of the bed underneath it, and something starts to smoke.

5

Deviance

Imagine, then, that rather than attending CES at the Las Vegas Convention Centre from chapter 1, you decide that you want something more exciting than – I don't know, an internet connected hat. Instead, head south down the dual carriageway of Paradise Road, past the Starbucks, past the Silver Sevens Hotel and Casino, until you get to a hotel with a gigantic neon guitar wedged on the asphalt outside. This is the Hard Rock Hotel which, until it closed for renovations in 2020, hosted the Adult Entertainment Expo (AEE) – the largest pornography trade event in the United States.

Inside there certainly is a lot of sex, gambling, and rock 'n' roll on show. There's a casino in the lobby – no, the casino *is* the lobby, decorated throughout with the costumes of famous rockstars displayed behind glass in gold cases. Positioned below a chandelier made of saxophones is what initially appears to be a massive golden Academy Awards statuette but on second glance is actually two people, clasped in a tight embrace. It's a human-scale version of the AVN Awards trophy that will be doled out at the awards ceremony that closes out the show. AVN began life as Adult Video News, the oldest and longest running pornography trade magazine that started out in the 1980s offering reviews of sex videos to video rental shops uncertain about which tapes to buy in for their customers. Now, renamed AVN, they run this annual show. The café here sells cupcakes with a red and white sugar-paste AVN logo wedged into the icing.

In one hall are the large and colourful stands of major production studios where contracted performers sign photos and pose for pictures with the snaking queues of fans. These photo-meets used to happen in a long corridor outside the hall, but that space is now taken up by a row of cam performers who work live, sit ting behind their ring lights. The area

showcasing ‘adult novelties’ – that is, sex toys – feels like it’s been generated by an AI model seeded with the terms ‘uncanny menagerie’: pastel stingrays, yellow hammers, glittery phalli, all gently quivering in the air conditioning. In the vast carpeted caverns of the hotel convention rooms, filled with crowds, nothing on show is particularly sexy at this very moment. Nonetheless, you do understand that forms of sex and sexiness are being sold which, in a different room, with different company, could unfurl into pleasure.

Down a corridor to the left, though, is a room where sexiness comes to wither and die. A banner of the AVN logo hangs on the back wall but otherwise you could be back at a seminar on litigation at CES. This is a world away from the spectacle of the previous rooms. Here, a stream of folks in suits and California smart-casual come to the dais at the front of the room and talk about what quite honestly is deathly dull stuff: tax, website hosting, insurance, more tax. This is the business-to-business part of the show, a reminder that however seamless the front-of-house stuff is for the customers, it is only made possibly by an industrial infrastructure running underneath it all, hosting websites, managing online traffic, remaining aligned with any regulatory changes and – most of all – managing the money.

AEE hosts its own business seminars each year, but there are also scores of dedicated adult B2B trade events which take place across the United States and around the world each year. Go to enough of them and you’ll see that money is the thread that runs through each event. This is, perhaps, unsurprising – the pornography industry may raise eyebrows with what it sells, but it is an industry, and a legal industry at that, and, without turning a profit, it can’t survive.

But – you may think, cupcake in hand – sex sells. Yes, like other sectors selling online material, the adult industry has been hammered hard by piracy, but surely sexually explicit material is in constant demand. You look around the room and wonder, could *you* make your way in this industry, selling whatever the erotic version of internet connected hats are?

Look again, because there is another, stranger, undercurrent of money here. It’s not just in the seminar titles which have names like ‘Ringing the Register: Smart Online Billing Strategies’. Look around the room, at the sponsor logos decorating the walls and the lanyards and the free swag, the pens and the paper and the tote bags and the squeezy stress toys and the

breath mints and the water bottles. These events aren't sponsored by content studios or internet companies. They're sponsored by payment processors – that is, the companies that sit between a customer and a merchant seller to verify whether a credit card transaction is legitimate or not.[1] In a sea of technology platforms and explicit content, we might ask: What are the financial service providers doing here?

Anthropologist Bill Maurer describes payment as the plumbing of modern economies.[2] Like infrastructure, the financial environment that the adult entertainment industry operates in is rarely acknowledged but underpins everything that it does. We can easily think of money as part of a system where institutions such as banks, insurance companies, and stock exchanges work in lockstep to define the value of money and determine who gets paid. But the structure of financial systems is only the starting point. The institutions which make money and make money move are not defined by idealised abstract economic forces, but are structures which are intractably bound together with social circumstances.[3] In short, money is made of people, and people have culture.

If systems are structure and behaviour, then let's think about which behaviours are driven through a system, and why. It may seem counterintuitive but the best way to do this is to look at who transgresses a system's norms. If you fit within the rules and expectations of a system, the world works as it should. You can marry who you want, buy what you want, live where you want and live how you want. What does it feel like to be normal? The answer is, it may not feel like anything at all. What is deemed to be usual is designed into a system so completely that, if you abide by its dictates, it just feels like everyday life. John Scalzi likens the experience to playing a computer game on the lowest difficulty setting – it's not easy but it is easier, and when you need help it's easier to get.[4]

If you transgress, the system shows itself for what it is.

The intersection of sex and commerce is an excellent place to look at what it means to be deviant in a system. It's near-impossible to talk about sex neutrally – sexuality is suffused with an excess of significance and supercharged with moral meaning.[5] A cupcake is one thing; a cupcake bought at a pornography trade event is quite another. Sexuality is also paradoxical in its powers, seen as something deeply private and personal

and yet, if unleashed, capable of dissolving society.[6] Sexuality is unstable, mediated by history and culture with no fixed relationship between acts and meaning, yet all-important.

Money, too, is made up and can only derive its power from collective social forces. As the anthropologist Lana Swartz explains: 'We accept money – it is only valuable – because we have a shared sense of what institutions authorise it, who will accept it and where, and that they will accept it tomorrow and the next day and the day after that. When we exchange money we agree not only on its quantity but its meaning.'[7] If you exist outside approved social norms, it's not a given that the institutions of money will recognise you. It is not a given that you will be able to get paid.

So: when sex meets money, what it means to be normal bites both sides. The intimate nature of sexuality contradicts the public free-market nature of commerce to the extent that they are often considered as 'hostile worlds' that should never mix.[8] But, for the sex industries, this mixing is the defining feature of their existence; as Melissa Gira Grant writes, it is the act of receiving money in exchange for sex that signals prostitution.[9] As we shall see, the modern American adult entertainment industry expands these activities out into performance and manufacturing, but has historically been governed by pornography regulations and the idea of 'community standards' – that is, shared local norms about what is acceptable and what is not. By bringing together commerce and sexuality, the adult entertainment industry remains highly taboo. Societal reactions to commercialised sex are oftentimes a mixture of moral revulsion and resigned tolerance.[10] This isn't only pearl-clutching; those who violate societal norms are also subject to societal punishment across every sphere of their existence.

Adult trade shows are canny pieces of experience design in that they feel as normal as they do. The customer-facing show has a similar manic energy and aggressive enthusiasm to other fandom expos, as crowds of fans, queuing since early morning, rush in to meet their idols for photographs and signatures, and head into panel discussions to hear them talk about their careers and the industry.[11] In the adult novelties section – not a million miles away from any of the halls at CES – you can handle the merchandise and ask the reps questions about user experience, materials, and the design choices that went into each artefact. It's only really at the fan-facing show where what the film scholar Linda Williams describes as

the ‘frenzy of the visible’ of pornographic material is on show.[12] Even then, what’s on display is muted: topless images of female performers rather than anything in motion and – as signs around the show emphasise – full-frontal nudity is banned on the show floor.

In the first few hours of being there, the combination of being surrounded by so much sexually explicit *stuff* in an otherwise standard Vegas hotel environment can be absolutely discombobulating. After a full day, some of the differential has worn off, and mostly all that matters now is your feet hurt from all the walking around, and the pints of iced coffee from the in-house Dunkin’ Donuts just aren’t cutting through.

In the B2B events, the businessfolk themselves have the usual round of lanyards, talks, state-of-the-industry discussions, networking breaks, and, after hours, go-karting and golf. One of the main differences between the two is that the business show is, necessarily, upfront about the challenges the sector faces – the visual branding of B2B shows is less nudity, more bar charts; no one is approaching any of the reps from the payment processors for a signed photo. But just because the product isn’t directly on show doesn’t change the fact that this is a different type of business – one where people have picketed previous trade shows, and the shops, and the cinemas that sell what the industry has to offer, too. The knock-on effect of these differences spreads throughout the sector and into the very heart of what a business is under capitalism: money.

Writing in 1963, the social scientist Erving Goffman described how people make judgements about each other as a means of locating them in the social order. ‘We lean on these anticipations that we have, transforming them into normative expectations, into righteously presented demands,’ he writes. ‘Typically, we do not become aware that we have made these demands or aware of what they are until an active question arises as to whether they will be fulfilled.’[13]

This is stigma: a powerful, negative, socially created phenomenon which transforms the stigmatised person from ‘whole and usual’ into someone stained, discredited, lesser in the eyes of society. Stigma had already been worked over extensively by psychologists who had identified the characteristics that could lead to social ostracism at the sharp end of a power dynamic, and are still familiar now: how you look, where you come from, whom you desire, where you work. Goffman’s innovation was to look

at the social structures in which these judgements were made. A characteristic was just a characteristic – it was society that judged it lesser and penalised accordingly. In short: systems make stigma. To make sense of stigma, Goffman argued, it needed to be understood as a structure of relationships, not as a singular attribute. These structures may have been grounded in social judgement but could also be wrapped up with policy and institutions. Someone might be made an outcast by society, but also find it hard to get housing or find a job or obtain healthcare, and so on.

Stigma can limit people's job opportunities, but what if the work itself is stigmatised? This is what the sociologists describe as 'dirty work'.[14] Sex work is the ground zero of stigmatised jobs, with its deviance – 'whore stigma' – grounded in illicit femaleness.[15] Sex work can never just be work in itself but, as Juno Mac and Molly Smith say, is a lightning rod for questions about masculinities, class, bodies, and of course work too. 'Sex work is the vault in which society stores some of its keenest fears and anxieties,' they write.[16] The work of sex spills across the show floors of AEE, from the big-name performers doing interviews, to the freelancers signing photos, to the livestreaming cam performers.

And yet – if I look around the seminar rooms at the adult business trade shows, the people around me work in marketing, or accounts, or sales – the most standard, even boring, jobs that you could find anywhere. So how does stigma exist within an entire workplace, then? Bryant Hudson and Gerado Okhuysen's wonderfully titled article, 'Not with a Ten Foot Pole', explores how stigmatised organisations survive and even thrive in the face of intense opposition.[17] Their focus is the gay bathhouse, whose stigma derives from the perceived sexual and gender transgressions which underpin homophobia, and (in the aftermath of the AIDS epidemic) associations with disease.

Stigma exerted strain on how bathhouses operated. Owners often had to do their own work in-house – carpentry, plumbing, painting – rather than having to settle for a limited pool of inferior external contractors. Even if suppliers themselves had no particular moral objections about working with a gay bathhouse, they were scared of what others would think of them for working with a gay bathhouse. We might call this network effects, but it's also what dirty work *does* – dirt stains others, too.

The improbable persistence of gay bathhouses, as Hudson and Okhuysen describe it, raises two critical points about stigma, systems, and money. First, one of the main effects of being stigmatised is that it hinders your access to resources and there are only so many ways that one can make up for this loss. A business owner might be able to find an individual friendly carpenter (Jesus, perhaps) to mend their roof, but it is much harder to find a sympathetic system. When a bias against 'deviant' sexualities is built into the very infrastructure of a financial system such that it affects who a bank will give a business loan to, or even who can open a bank account, it becomes much harder to push back against. The cost exerted by stigma goes both ways: many suppliers would rather take a direct financial hit than work with, or be seen to work with, a stigmatised business, which itself might bring more financial damage later down the line.

The second point is about advertising. If you're interested in how stigma operates at the industrial scale, adverts are a really great place to start. A deviant business such as a sex shop that's trying to exist in the mainstream world can use a number of different practices to survive, whether by using plain storefronts, low-key packaging, or discreet side-entrances for customers to enter and leave from – a theatre of appearing as normal and non-threatening as possible to a potentially hostile audience. But in an accepting environment – in the right part of town, or within the pages of an industry magazine, or at a B2B trade show – stigmatised businesses and their associates are free to express themselves as they want. They may not even be stigmatised at all: one of the original examples of dirty work is of casino managers, which seems ludicrous in Las Vegas. Who *wouldn't* want to be boss of a massive, mirrored pyramid in the middle of the desert that shoots a beam of light into the sky each night?

So, advertising and sponsorship shows where money moves and which organisations are willing to be publicly associated with a deviant sector. In a single moment, they present a relationship of some flavour between sponsor and subject. Sitting in the convention room of the Hard Rock Hotel, it's clear that payment processors are linked to the adult entertainment industry. Tracked over time, advertising also indicates where and when these relationships emerged and what the general vibe of a sector is. As well as picking up tote bags of flyers and merch from trade fairs, I've also spent a fair whack of time digging through archives of adult industry trade magazines – not the erotically focused ones, but the business-facing

publications like AVN. Read the archives and what becomes apparent is how many of the advertisers present themselves as sympathetic to the industry; industry insiders even. Some play it straight and offer up their services of stackable high-capacity DVD drives or as an accredited registrar for the short-lived '.xxx' domain that was meant to silo adult companies away from mainstream dot-com sites. Other adverts are properly funny in the way that only an in-joke can be. My favourite is still that placed by a composer, cheerfully asking: 'Looking To Score . . . your next feature? High quality electronic music available for your videos. All genres, competitive prices.'

Trace the archives with an eye to chronology, however, and a particular pattern emerges. A line of technological want runs through the decades, through the writing and the advertising. 'The Future is Obsolete', one piece begins: 'By the time you read this article, it will probably be outdated.' 'INNOVATE: Push into the future', urges another, accompanied by a stock photo of a group of middle-aged men in suits cheerfully riding Segways. Up until the mid-Nineties, the flavour of nearly every 'yet another next-big-thing' jumped on is a communication technology, whether CD-ROMs, DVDs, or the extremely exciting 'Virtual Max 3D Glasses' (tagline: 'When You Go To Bed, All You Need To Wear').

For several decades, the major stress-point in the adult industry was production and distribution. In the Golden Age of 1970s pornography, full-length, high-budget narrative driven hardcore films were released in movie theatres; mostly adult-specific but some, like *Deep Throat* crossed over and were shown in mainstream venues, doing $30 million in ticket sales. Takings were high for producers but didn't result in better working conditions for performers.[18] If you wanted to watch porn, you'd buy a cinema ticket with cash – an easy transaction.

Then came the Silver Age, beginning in the late 1970s as video entered the market. Producers could now sell either direct to customers or via intermediaries such as mail order catalogues or rental stores. Movie theatres clung on but were rapidly usurped by VHS and home video recorders (and, briefly, Betamax). Now customers could easily buy or rent videotapes at their discretion.

This state of affairs was stable for nearly two decades – if anything, the industry was a victim of its own success. Blockbuster Video launched in 1985 and refused to stock adult videos as part of its 'family friendly' policy,

but this just gave more business to independent stores who could now distinguish themselves as places where customers could access porn. The industry infrastructures of the adult trade show that we're strolling around in Las Vegas were set up in the Silver Age. As we've already seen, AVN was originally founded to provide video store owners and their customers with reviews of the growing number of adult videos.

The trade show itself is a direct descendent from the time in the Silver Age when adult companies exhibited at the East Coast Video Show (ECVS) and the Video Software Dealers Association (VSDA) – originally hidden away in a backroom, but later given space in the main section of VSDA as the first booths that visitors saw when they arrived. 'The adult industry is significant to the video industry,' the show director explained. 'It's vital to the many small retailers who depend on that revenue. Therefore, it's a significant component of the show.'[19]

Looking through the adverts in the back issues of AVN over this period reveals an industry that is mildly concerned with communication technologies. Would customers make the jump to DVDs? Who would manufacture pornographic DVDs? Would rental stores have to buy new storage units for DVD cases? And so on. Some advertisers made it clear that they knew that their potential clients were stigmatised, and they didn't much care: 'WE EDIT ADULT! DV (mini or full size), Hi-8, BetaSP, SVHS, or 3/4 – WE EDIT IT ALL!' reads one ad. Computers were only on the scene inasmuch as they might allow customers to watch some of those new-fangled discs. Writing in 1993, the AVN editor Mark Kernes offered up the image:

> Picture this: you go out to the mailbox and find that your new copy of AVN has arrived, so you take it into the house, fire up your computer, drop the shiny silver disc into your CD-ROM drive, open the document and start reading – or let the computer read it to you.[20]

If anything, the real worry of the adult industry by the mid-1990s was that it was churning out too much material. Between 1994 and 1995, the amount of new releases jumped up 79.1 percent. Handheld video cameras had made it considerably easier for anyone to make their own movies and, while the large studios continued to be profitable, industry observers were getting twitchy: customers could only buy so many videos. 'Where is all the product going to go?' one editorial asked.[21]

And then, in response, the internet.

If we look at the early years of online pornography via communication technologies, we see a sector in flux; nothing really so different from how other industries have been thrown into turmoil by disruptive technologies, though. There's a lot of noise out there about how the porn industry has some instinctive relationship with technology that allows it to drive and respond intuitively to emerging innovations. This is, for the better part, nonsense; or, with the most generous reading, a misunderstanding of how the industry operates. If we were to generalise, we could say that technological advancements which allow for private, isolated consumption of pornography have been rapidly adopted, though rarely created in-house; and that the sector itself has a slippery relationship with doing things by the book, which is often mistaken for preternatural talent.

Even so, each transition has been difficult. As the internet swung into view, incumbent firms were hesitant in committing too quickly to any new platform. Though desktop computers were becoming more prevalent they were still expensive, with slow bandwidth and horrible image quality; in those early years, there was likely more of an erotic thrill in imagining what might be glitching slowly down a screen than from the actual image itself.

So, *Playboy* set up its first, shaky website in 1994. AVN followed suit in 1995, together with careful instructions about how to type a URL into a browser: 'Just fire up your modem, open your Web browser, select "go to" and type in "http://www.avn.com" (without the quotes, of course).'[22] As the studios held back, a shoal of newcomers rushed in. An entire back catalogue of sexual material was up for grabs to be digitised and flung online by bootleggers: not only movies but a mass of pictures taken from books, magazines, postcards, video stills, even personal photography. The scale of the onslaught was too much for incumbents to handle; major pornography producers saw decades of their work stolen and resold, with little recourse.

But the biggest financial problem for anyone who wanted to sell porn online wasn't theft. The biggest problem was how to pay.

An interesting thing about trade-fair swag is that it remains constant, no matter which industry you pick it up from. In a box under my desk, now, are: a stress-toy squeezy rabbit, a tin of breath mints, a towel, a combined tape-measure and spirit level, lip balm, an enormous amount of pens, and

more – only the branding indicates whether they came from AEE, World of Concrete, or the SHOT show.

And yet, no matter the object, nearly all of the adult industry merch is marked with the names and logos of payment processers – Netbilling and CCBill show up a lot, but CommerceGate, Paycom.EU, ePayCompany, Payoneer (Tagline: 'The best way to get paid, no matter where you are in the world'), Epoch, and webbilling are also along for the ride. There's little to differentiate one from the other: all tend towards neutral colour schemes of blue or grey, with similar offerings of 'alternative payment methods', 'payment solutions', and 'billing solutions', all rotating through the same industry awards for 'Best Alternative Payment Company' and 'Best Alternative Payment Systems of the Year'. Though their branding is plastered everywhere throughout these shows, it is background, safe, sterile.

These companies have a similar mouthfeel to other platform infrastructures – Microsoft, Dell, Intel – that prop up the technology industries (although you would never in a month of Sundays see the likes of Microsoft advertising at AEE). In pornography, payment processors are the infrastructure. Though their branding identity may seem blandly timeless, many emerged in the late 1990s as the adult industry hit the realisation that although you could fill cyberspace with pornography, finding a safe and stable way for people to pay was far harder.

To begin with a very obvious point: it's nearly impossible to pay online with physical currency, unless you want to run the risk of sending cash or cheques halfway across the country or beyond to a vendor. In the early years of the internet this is precisely what people buying things on eBay had to do, but we'll come back to them shortly. Realistically, from the mid-1990s onwards credit cards were the only game in town – a form of electronic payment that could neatly slot into the digital infrastructure of the internet. This may seem pretty straightforward – I'll hazard a guess that most people reading this have bought something online. It's a painless process with the only friction coming in the slight wait between typing in the payment details and waiting to see if it will be accepted. In that small wait, though, there is an entire world of social attitudes to money.

Lana Swartz puts it well when she describes how, once you stop using cash there are no clean lines of payment available: every step in the process gets bound up in the technical infrastructures of banks and processors.[23] When a payment moves digitally through a system, the action is no longer

about a direct exchange of money for goods and services, but instead involves a series of different nodes carrying the risk for this exchange up and down the chain.

Some payments are more of a liability than others. The companies that run credit card programs, including the major players of Visa, MasterCard, and American Express, are acutely attuned to how their services are used, and by whom. Under Merchant Category Codes (MCC), some sectors as classified as ‘high risk’: those which test the boundaries of social norms while remaining – mostly – legal. Pornography resides here, under MCC 5967, together with horoscope readings, firearms, herbal remedies, counterfeit luxury goods, and psychic phonelines; an alliance of the dubious.

But ‘high risk’ is not stigma. Seemingly innocuous services such as travel agents also fall under high risk MCCs. What binds this disparate group together is not their products or services per se, but how they are affected by threats from third parties – that is, how they exist within a financial system. A high-risk merchant is more likely get tied up in money laundering or data theft, face financial issues due to unforeseen circumstances such as rapid shifts in regulation, or just attract dodgy customers. Greatest of all of the risks, though, is the chargeback – when a customer disputes a credit card transaction, and the money is returned to them. The relationship between risk and chargebacks is circular – chargebacks are more common in high-risk industries, but chargebacks are also how a high-risk industry is defined.

Chargeback laws were implemented to protect customers from fraud. Chargebacks are most likely to happen in ‘card-not-present’ situations – that is, through online payment. And nearly 80 percent of chargebacks result from card fraud – either stolen cards, or so-called friendly fraud, when customers don’t recognise a strange item on their credit card bill, or just forget that they bought it. The structure of chargebacks relocates transactional power from the merchant – who might at best refuse a refund and at worse, vanish into the night – back to the customer. If your credit card gets stolen and used to purchase a sack of porn, you should be able to claw that money back eventually.

Chargebacks are annoying for everyone – they’re time-consuming, requiring an entire arbitration process to be set up, and they force an unsettling flux in a system designed to funnel money rapidly from customer

to merchant. But for merchants, chargebacks are a real pain in the ass. Not only do they lose profit and, potentially, product, but they also have to pay a fee to their payment processor. The closer your chargeback rate is to zero the better, and most merchant accounts consider a 1 percent rate as the maximum tolerable.[24] The riskier you are, the harder it is to operate because your options around payment are limited – many financial institutions refuse outright to work with high-risk merchants.

This, then, is where those payment processors we've seen stamping their logos across the trade shows come in. They intentionally specialise in high-risk accounts: they are the risk-eaters, the arbitrators of bad fortune, the facilitators. Without these organisations, the pornography industry grinds to a halt – porn itself can continue to slosh around the internet, but no one can buy it. It's important to note here that that high-risk payment processors aren't doing this out of the goodness of their heart, any more than their counterparts reject adult customers based on specific judgements of moral turpitude. Instead, they work to business models constructed under a systemic calculation of how a stigmatised product exists within the grey moral borderlands of capitalism.

Specifically, they were set up deliberately to take on the new risk of online pornography. CCBill, NetBilling, and Paycom were all founded in 1998. At the top of the chain, in the upper echelons of the credit card issuers, American Express stopped taking payments for pornography in 2000 – not ostensibly for any moral reasons but because the time and energy spent resolving cardholder disputes wasn't worth whatever gains were made legitimately.[25] Visa and Mastercard stayed the course, passing down its edicts on how payment processors should behave. One of the largest high-risk processors in the late 1990s, Web800, was forced out of business after losing its Visa account when failing to address its high levels of chargebacks.

In turn, high-risk processors passed on their own orders down to their customers. Shouldering the cost of risk was one part of this, charging high fees for their services; sometime even demanding that their customer keep a certain percentage of their turnover on hold as a rolling reserve, so that if something went wrong the banks could secure their losses. But processors could also exert control over adult products. In 2005, CCBill updated its acceptable use policy to exclude 'person-to-person exchanges of bodily fluid [including] urine/urination, blood, or overall violent scenes'. No

explanation was given for the change, though industry news sites speculated that it might be tied to the formation of an Obscene Publication Task Force that same month.[26]

Opacity was enough to limit what could be shown: the British producer Pandora Blake, whose site focuses on corporal punishment, has described the difficulties in meeting CCBill's requirements, when the company's terms and conditions are imprecisely defined and inconsistently enforced, seemingly on a whim. When asked why they didn't change billing provider, Blake responded:

> Firstly, I am using custom software designed to interact with CCBill's API and I don't have thousands of pounds to spend on hiring my developer to rewrite it. Secondly, CCBill is the preferred billing agent of most [resellers] and I would lose a lot of business if I changed to a different provider. Thirdly, other billing agents are exactly the same.[27]

Pity then the poor newcomer who rocks up at their first adult industry trade fair, expecting an easy ride in selling their wares, in an atmosphere full of [redacted redacted redacted] and hot tubs. Instead, they find themselves in a chilly, over-airconditioned conference room at 10 am in Tempe, Arizona, sitting through a seminar thrillingly titled something along the lines of 'E-Billing: Strategies for Greater Profit'. It opens with the founder of a payment processor stating, as he gestures to representatives from other payment processors on the panel in their branded polo shirts and chinos: 'We have all been in this business for many years; we're trustworthy companies and we'll also continue to be here for many years.'

The tedium of these sessions is perhaps why those squeezy stress-toys are up for grabs, and there are many, many such sessions. Every show has a '101' introductory talk to bring newcomers up to speed on – well, all of this. For industry members, trade shows are the rare occasions when they can actually meet a processing rep face-to-face. For processing reps, trade shows are a captive audience of potential customers, all there to be sweet-talked into a contract.

Beyond the branded bunnies, let's go back to those flyers and banners from financial service providers wallpapering the show. Here's one from Humboldt Merchant Services which states: 'Some call your business high risk. We just call it business.' My first impression of this had been that it fell in line with ads from other service providers who wanted to emphasise that although they knew their clients were heavily stigmatised, they

wouldn’t hold it against them. ‘Tired of hosted software that prohibits terms like “pornography” and lump your business with illegal activities?’ another company asks, in a print ad. ‘You won’t have that problem with YNOT Mail. YNOT has been a trusted brand with adult industry professionals since 1996.’ This offers a sell to potential customers that although working in a deviant space means things have to be done slightly differently, they’ll still be treated well.

Why are industries such as pornography more prone to chargebacks? Though the category of risk is not the same as the phenomenon of stigma, the two brush up against each other. From the adult industry’s perspective, ‘intentional chargeback fraud’ is part of the territory – this is when a customer falsely claims a transaction was fraudulent, even though they made the purchase. You can easily imagine how this goes: the customer who is too embarrassed to admit that that they bought a three-month subscription to ‘Red Hot Marxxxists’ insists it must be fraud.

But the adult industry also misbehaves. It may be legal, but a chunk of its operations are still at the scrappier ends of the scale of professional behaviour. Deviant organisations find it harder to hire people – *good* people – who are willing to come in and absorb those reputational risks into their career paths. As I mentioned earlier, what is often framed as some sort of natural affinity with emerging technologies is more, I think, a devil-may-care attitude around business behaviour. As we’ve seen, the earlier years of online pornography were characterised by theft and chaos; a period which industry members refer back to as the ‘Wild West’.

During those years, in the midst of the dust being kicked up, it could be hard to tell who was ripping off whom. The dirty tricks of the early online era included asking customers for credit card details, and then making unauthorised payments; copying the card on to a different site; continuing to charge customers for lapsed subscriptions; or obscuring how long a membership period was.[28]

By the late 1990s, several payment processors pressured adult entertainment companies to withdraw their strategy of using free content trials to attract customers, requiring them to hand over credit card details. This had backfired: as the trial period ended, payment kicked in, customers demanded refunds, and chargebacks soared. This came to a head at a heated e-commerce seminar at a trade show in 1999. The write-up of the event from *AVN* described how tempers flared: companies blamed customers for

‘pretending not to understand what “free” meant’; but the processors argued that adult companies had been evasive about what they were charging customers. The payment processors triumphed, and the strategy was dropped.[29]

It took me longer to figure out why payment processors were so fervently selling themselves as trustworthy. The answer takes us right back into the systemic nature of stigma and how it stains. Look again at that bag of swag and ask: is it only pornography companies that are stigmatised here, or does that mark of disgrace carry from the pen from Wicked Pictures over to the pen from NetBilling? To put it another way – when we talk of the ‘pornography industry’, do we mean film studios and performers? Or might we also include web-hosting platforms, financial services providers, marketing agencies, and all of the other companies that make an industry an industry?

At the industrial level, the lines between what is stigmatised and what is not become harder to parse. The sociologist Jean-Philippe Vergne states that a stigmatised firm is not a stigmatised industry.[30] His research focuses on the vendors at one of the other trade shows in town, the merchants of death: the defence industry. As a whole, the sector is reviled, from weapons manufacturers to the wider network of think tanks, journals, research groups, and more. But look closer: weapons producers aren’t always weapons producers.

Take Boeing: in the defence sector, the company consistently ranks in the top three largest arms producers worldwide, and yet manages to keep its disapproval rating lower than its counterparts. The reason is obvious – say ‘Boeing’, and people are most likely to think of commercial aeroplanes. The fact that the company also uses its knowledge in aeronautical engineering to create machines of destruction doesn’t seem to cross most people’s radar; the association with 747s is strong enough to dilute any link to war.

The argument that Vergne makes is that, to an extent, it doesn’t matter what an organisation in a stigmatised industry *does* – what matters it how its seen and then categorised. In the adult entertainment industry, this divide is most obvious in the split between sex toys – or ‘adult novelties’ on their LinkedIn account – and everyone else. At AEE, sex toys are parcelled out in different halls from the performers and, at other points in the year, take

over the Los Angeles Marriott Burbank entirely as the Adult Novelty Manufacturers Association.

In the United States, sex toys have clawed their way into mainstream commerce through concerted effort by their manufacturers and retailers to reposition them not only as normal, but healthy; led by the desires of female and queer customers for pleasure and self-actualisation, an inversion of the gross gendered power dynamics that the mainstream pornography industry is mired in.[31] More recently, 'sextech' and 'sexual wellness' have come to define this space as a sector which spills over past healthcare into tech and pharma. And yet, for all of this, business owners in sex toys, sextech, and sexual wellness describe how their companies are seen as unclean. The entrepreneur Andrea Barrica describes how her company is still routinely grouped together with porn, weapons, and gambling (welcome to Vegas) as 'society has deemed what sexual wellness companies do as "immoral" and therefore demands it to operate underground and in the dark'.[32]

Under the auspices of 'high risk', payments processors lump together all parts of the adult industry, from pornography to novelties, and even to dating. I picked up a series of flyers from a 2013 event that CCBill had created for each of these segments; in the lower right-hand corner on the dating-focused leaflet, 'Upsell Love', is a tiny textbox bearing the caveat: 'Note: Mastercard considers any dating site to be high risk, even if the site offers services that are not of traditional adult content.'

But what of payment processors themselves? Stand back a moment and reframe that picture. What if, instead of being the dour outsiders with their bland blue branding, emphasising that they *really empathise* with how difficult it is to be different, they were part of the adult industry too – not because of how they're perceived, but how they behave. Seen in this light, the emphasis on being steadfast and reliable comes across not as the pat on the shoulder from the grizzled old bank manager in fine tweed, but the pleadings of a loser boyfriend after one indiscretion too many.

Trawling back through the back issues of *AVN* reveals a horror show of bad behaviour, of collapsed payment processers and destitute customers. There's GloBill, which shut up shop in 2003 but not before releasing a statement bemoaning its fate: 'In what we believe is an unfortunate example of Visa abusing its power in a stunningly arbitrary and patently unfair manner, we were advised that our bank was instructed to terminate our

processing in order to avoid threatened fees in the hundreds of thousands of dollars.'[33]

Adult companies were advised to avoid cashing any payout cheques which they already held and instead write to GloBill's corporate headquarters in order to get paid. The company had registered its headquarters in St Kitts, a beautiful Caribbean island which was also, an industry writer archly noted, home to a dormant volcano and favourable offshore tax regimes. Those out-of-pocket folks chasing their money? 'They sometimes hear back.'[34]

Then there was iBill, which went out of business 'slowly and gracelessly' in 2004 when its contract with its bank expired before being bought out as part of a larger acquisition which also included *Penthouse*. Payments weren't released for another eight months, with *AVN* tracking the story under the headline 'I Bill, You Bill, We All Scream For iBill'.[35] Its processing was later outsourced to another offshore provider before completely vanishing, its homepage replaced by the adult blog 'G-Spot News'.[36]

Payment companies could become embroiled in the same chaos-state as adult companies in the early 2000s, but adult companies also, sometimes, set up their own service providers, by necessity. Each time a payment processor lost its wings, firms across the sector scrambled to find replacements, as one founder explained:

> Initially we were doing the bulk of our billing with [a high-risk processor] until they went out of business one year, the day before Christmas. We realised pretty much straight away that we'd have to build our own billing system to give us exactly what we wanted and not be relying on everyone else . . . All of the [other] companies were working on their own billing systems at the same time because everyone had been dependent on the guys that went down.[37]

So, no one was having a good time of it. Adult companies were beholden to processors which might collapse at any time to stay in business; processors were required to keep adult companies in check, demonstrating that their clients weren't actual criminals – not so much nested reliances but a full rat king of money and culture, all twisted and knotted together.[38] In this light, a paragraph in a flyer for a merchant services provider makes more sense. It read: 'As other credit card processing companies are abandoning the

industry, Humboldt is continuing a twenty-year tradition of standing behind adult merchants.'

Hovering benignly above it all are Visa and Mastercard – the credit card issuers who had stayed the course; who, over the years, set down increasingly stringent regulations; whose logos are nowhere to be seen. You could go to every single adult trade show and read every single issue of all of the industry trade magazines for a year, and never encounter a single advert for either.

Depending on your perspective, this may seem like either a bleak, or fitting, endpoint to this story – pornography trapped eternally in Sisyphean loop of co-dependency with payment processors. But this raises the question: isn't there an easier way of doing all of this? For an industry which seems to swim easily alongside new technologies, surely there must be some digital occult way of bypassing the nested legacies of credit cards and risk assessment – not necessarily a completely new financial system but at least something novel which cuts through the snarl-ups of the old?

None of this is wishful thinking. The technology studies scholar Antonia Hernández has written about the various attempts by sex workers to bypass financial infrastructure over time, from the coin-like objects which have been interpreted as a form of currency used in Roman brothels, to similar coins used in mining towns, up to the types of digital 'tokens' used today by sites like Chaturbate – a live platform which has no contractual liability to its performers and controls payment through its own, contained, currency.[39]

Away from adult material, you've almost certainly paid for something online using PayPal, or Stripe, or maybe with your phone or watch using Apple Pay or M-Pesa – financial systems which let people transfer money directly from their bank accounts, or even phones, without getting tangled up with third parties. When the internet came along, the adult entertainment was not alone in being stymied in trying to figure out how to sell things online.

eBay, founded in 1995, had wrestled with payment. Facilitating credit card payment exposed the company to the risk of transaction fraud but most eBay sellers had too few sales to qualify for a merchant account. Customers were left to pay using cheques and postal orders, mailed across America. In this upheaval, the possibility of throwing everything up in the air to build a

new system of the world took flight. This desire seeded the construction of PayPal – one the first new financial platforms built specifically for online space.

PayPal began life as Confinity – a venture set up by Peter Thiel in 1998, together with Max Levchin and Luke Nosek. Originally intended as a form of security software for hand-held devices, the company pivoted into a platform for transferring money in 1999; and, in 2000, merged with X.com, an online banking company founded by Elon Musk. On the surface, PayPal appeared to be a new branch of financial infrastructure, permitting people to send money directly to each other via their electronic devices, without middlemen.

In its first iteration, customers could beam cash to each other between PalmPilots, like a financialised version of *Star Trek* teleporters. Unfortunately, beyond the Bay Area, Palm-Pilots were as rare as teleporters, and so the product shifted into something functionally similar to the platform we know today wherein anyone with an email address and a bank account can transfer money. It seems simple; it *is* simple, and the venture was well-timed. Unlike so many of the offerings of its dot-com peers – technically competent but serving no particular purpose beyond the fever-dreams of its founders – PayPal contained the seeds of a good idea.

Under the bonnet, however, Musk and Thiel wanted something bigger, something more disruptive – to remake finance from the ground up. ‘PayPal had a suitably grand mission – the kind that post-bubble skeptics would later describe as grandiose,’ Thiel writes in his memoir: ‘We wanted to create a new currency to replace the US dollar.’[40] The idea was bold, but the company struggled to find a sustainable business model. Larger online companies such as Amazon had the scale to lean into existing financial infrastructure and allow their customers to pay with credit cards; and so PayPal began to explore the spaces where online payment was more difficult. After initially sniffing around eBay but finding it lacking in size, PayPal slid over to the other white meat of e-commerce: online pornography.

I stumbled across the PayPal-pornography link in – where else? – the back issues of *AVN*, with the headline: ‘PayPal: The adult industry’s new friend?’. My first thought was that this was yet more wish fulfilment; an outsider company which the industry had caught wind of in the hope of saving it from its dependency on payment processers. Instead, it transpired

that PayPal was one of the few mainstream companies that had – for a very brief time – not only worked with pornographers, but also seemed to actively, openly woo them.

From the perspective of the adult industry this was an unexpected but welcome lifeline into new forms of payment and perhaps even overlapping ideologies; the credo underpinning PayPal's own purpose to exist beyond state regulation and control mirrored pornography's own libertarian tendencies. PayPal carefully extended its tendrils. Reps travelled to trade shows, and the company began to permit payment for adult content. These were small and guarded movements: a report from a trade fair in 2002 quoted a PayPal representative saying: 'While the company wants to take a cautious step into the adult industry, it doesn't want a flood of adult accounts to crash the door.'[41]

The view from inside PayPal was, however, quite different, as the company's former marketing executive Eric M. Jackson recounts in his book, *The PayPal Wars*. The company had already experienced its own shockwaves around risky marketing when Confinity had merged with X.com. Musk insisted that that the company keep his 'X' identity and rebrand as 'X-PayPal', convulsing his colleagues as he alone appeared to either not know or care about the specific connotations that 'X' shared with the sex industries and which everyone else was keen to avoid.[42]

In public, PayPal spoke of wanting to be the financial operating system of the world, the 'Microsoft of payment', but this type of thrusting talk avoided the reality that any association with pornography could stymie this dream. Maybe most of all, the company's employees were profoundly discomforted by this strategy – talk of expanding into online gambling was seen as acceptable but pornography was out of the question.

This discomfort didn't last long. The relationship between PayPal and pornography ended in 2002 as *AVN* sadly reported: 'eBay Buys PayPal: Will restrictions follow?' Yes, came the answer. Payments to adult clients were promptly stopped, as the company announced:

> Like any company, PayPal has to find the right balance between serving the needs of a large, diverse group of customers, and minimising financial risk. Over the last several months and years, there's higher financial risk associated with adult. And [adult's] actually a very small part of PayPal's business[43]

And with that, PayPal skipped off into the sunset. But, though its foray with the adult industry was brief, we can learn something crucially important here about what the penalties are for deviance, and for whom. Over two decades on from PayPal's sale, and Elon Musk and Peter Thiel are firmly back in the realm of CES, both men lauded as visionary and deeply controversial billionaire entrepreneurs, made so by the vast wealth derived from the sale of PayPal.[44]

As part of his portfolio of companies and investments, Thiel founded Palantir – a militarised data-analytics company which neatly fits into Jean-Philippe Vergne's rubrics around stigma and identity. A vanguard of surveillance capitalism, Palantir sublimates its deviant identity through state-sponsored support and a technological skills base. To its marrow, Palantir exists within the military-industrial complex: one of its first customers was In-Q-Tel, the venture investment arm of the CIA, and one of its major products has been the predictive surveillance technology used by the Department of Homeland Security in deportations.

Musk's own ventures have been comparatively less grim and more performative: energy storage, tunnels, cars (electric, autonomous, and, sometimes, exploding) and social media. But the man himself has transformed into a C-suite edgelord; what Ian Bogost describes as the portmanteau 'bullionaire', a bullshitter who, through his fortune, has the potential to make his provocations real. In 2023, Musk revived the 'X' to rename the social media company which he'd bought earlier that year for $44 billion. As Bogost writes: 'Money talks, and bullshit floats.'[45] Sometimes, dirt can be desirable.

Yet this goes beyond the ways in which wealth can enable and forgive terrible behaviour. To remind ourselves, it's not about what an industry *does*: it's how it's perceived, and these behaviours can be traced back far further, to the inception of PayPal itself. You want financial risk? PayPal blew through its initial investment capital many times over, burning through a reported $10 million per *month* on sign-up bonuses and credit card processing in early summer of 2000, as it scrambled around for a sustainable business model; and still, venture funds were willing to throw it all at people who looked and sounded like what they anticipated a successful entrepreneur should be.

Even if this could be written off as the overenthusiastic japes of young men high on the fumes of venture capital, other behaviour was considerably more malign. Prior to its sale, PayPal was reported to have stolen ideas from another finance venture, dotBank; and had mulled over using digital sweatshops in Asia to buy eBay auctions to raise interest in their product, before deciding to build an automated bot to do it instead.[46]

The journalist Max Chafkin makes the case that PayPal's real legacy is ethical, not financial, disruption. The company had got as far as it had by doing things that normal, self-respecting companies of the early 2000s were too proper to try. 'Today,' he writes, 'the use of unsustainable or ethically dubious tricks to get a start-up off the ground is widely accepted – even celebrated in some circles of tech – and has been widely credited to . . . Thiel and his peers at PayPal.'[47]

The message from financial service providers to appeal to and reassure pornographers could equally well apply to the boy kings of Silicon Valley: 'Some might call your business high risk. We just call it business.'

Maybe then, after a couple of days at the adult trade show, you decide that this is all too complicated. Disruption sounded fun but the reality of being genuinely, structurally on the outside of a system is actually a lot of work. To be honest, you'd rather be rolling around in a ball pool sponsored by a search engine; and so, you head back to CES.

But the system has shown itself to you now and what was previously hidden cannot now be unseen. In the taxi rank outside the convention centre, you see that a cryptocurrency is advertising on the LED taxi tops on the cars. Looking around the robotics area, you realise the lack of sexual wellness products – those strange little robots on show at AEE are scarcely to be seen here, despite the technology functionally being the same. You remember what happened to Lora DiCarlo – the sextech company whose Osé personal massager won the 'honoree' designation in the robotics category of the CES Innovation Awards in 2019. The reward was promptly retracted by the Consumer Technology Association, citing rules that products which were 'immoral, obscene, indecent, profane, or not in keeping with CTA's image' would be disqualified. Although the retraction was itself later retracted, and CES changed its rules to allow sextech on the show floor, there is little of it to be seen.

Now, of course, you know why: as stigmatised products, sex toy manufacturers struggle to get funding or to be taken seriously, and even if they do make it into production, they can still stumble in getting their goods into the hands of consumers. If you want to walk around a specific area for sex toys, you'll need to leave CES and go back to the dedicated sex industry events. Sometimes this shimmer between desired and despised disruption, between financial and reputational risk, collapses.

And maybe, when you tap your card to pay for a cupcake from an independent vendor with adorable branding, you'll think about what can be bought within these systems. This is Nevada, the only state in America where sex work is legal – but regulatory infrastructure doesn't always overlap with financial infrastructure. Small bakery businesses may choose to use Stripe or WePay because it only requires software and a card reader to get going. Pornography and other sex-related products, however, are predominantly banned from these platforms. As a result, individual sex workers may find it impossible to get paid through digital financial infrastructure – not earning enough revenue to set up a contract with a payment processor and banned outright from working with payment start-ups.[48]

As Lana Swartz points out, this is a fundamental shift in how risk gets managed. 'High risk' was never meant to be a mechanism for exclusion, but a category for pricing.[49] Any company in the adult industry can ultimately get paid if it's willing to pony up for processor fees, but payment start-ups such as Stripe outright veto anything that would be considered 'high risk'. Under these start-ups' Terms of Service, an individual sex worker can be abstracted down into a series of risk factors – and, even if they try to obfuscate the nature of their work in order to earn a living, their online behaviour can be monitored by the types of surveillance tools on display at CES. Commercial sex, Melissa Gira Grant reminds us, is both a practice and an industry: though the practice of sex work may be legal, a member of the industry may be hindered in their ability to get paid.[50]

Back on the show floor, fintech stands proudly declaim crypto as a 'Disruptive Tech Trend', and yet here they are, comfortably marketing their wares alongside autonomous crop sprayers and what is apparently the first laundry detergent for space travel.

This is a very comfortable form of disruption, where risk gets costed in through hype and technological exceptionalism, and deviance is transmuted into acceptability as it intersects with power structures. Money operates within culture and culture is made by people, and when those people are regular Joes who just happen to be making up a new currency? Well, we can find a way to make that work. Under the showboating of revolution, most cryptocurrencies are still pegged to a state currency, tethered to an already-stable financial system. And if you've got a business and you'd like to offer your customers the possibility of paying in crypto?

Under the Visa Merchant Category Codes 6051 and 6012, cryptocurrencies are classified as 'high risk' – but there are plenty of payment processors in town to help out with that.

6

Breakage

Late summer, a swelteringly hot afternoon in South East London, and my friend Oliver and I are sitting in the over-heated basement of an institutional building that sits alongside a huge and complicated roundabout structure. This road system is incredibly poorly designed, having been the site of numerous accidents as cars and buses misalign themselves in the wrong lane; even walking into this building involves sharp near misses with cyclists belting round the tight curve of a bike path that has stupidly been built directly in front of the main entranceway. Through the windows comes the muted roar of vehicles and fug of exhaust fumes which acts an unexpected sensory accompaniment to what we're watching on the laptop. We are researching the largest and most expensive industrial automotive accident in recent history; we want to know what happens when cars break.

Car crashes are spectacular and terrible. The thrill of watching speed racing, whether Formula One or the Fast & Furious franchise, comes both from the pleasure of seeing beautifully engineered sleek machines pushed to their limits but also for the horrible possibility of the crash and the explosion, as thousands of pounds of steel and petrol move past the point of human control to be acted on by the physical laws of the universe. Outside controlled entertainment these accidents tend to be seen in the horror of the aftermath, as a pile-up on a motorway and the subsequent news report.

For a more humane viewing spectacle, there are tons of car crash testing videos online. In slow motion a car will ascend the side of a steep ramp before slipping and flipping over itself, wheels in a slow swivel. For a moment, the metal hulk is weightless, transcendent. And then gravity takes hold, and the car comes crashing back to earth again.

There are no astonishing crashes documented from the largest and most expensive industrial automotive accident in recent history, which involved a breathtaking eleven million vehicles. The videos which Oliver and I are watching do not show cars slamming head-on into walls, the metal of their bonnets rippling like silk (although as we'll see, the provenance of this scandal calls back to the heritage of crash testing itself). Instead, we are watching videos of men in plain suits explaining, obfuscating, and apologising. The films contain hours and hours of senior executives justifying their employer's actions to executive committees, or to crowds of journalists; standing in drab government rooms in Washington, DC and London, or in front of a wall covered with their company's logo: Volkswagen.

The setting is, of course, the Volkswagen emissions scandal of 2015, in which millions of vehicles were built that excreted higher levels of nitrogen oxides in their exhausts than were legally permissible. Despite the scale of the event, there is nothing really to *see* of the catastrophe directly: no fires or black clouds of smoke, only invisible fumes and, at the heart of the breakage, chunks of software embedded into the Engine Control Unit, a small piece of hardware that controls what the vehicle engine does.

Hence, Oliver and I are scraping through hours of government hearings and media interviews and internal marketing bumpf to try to get a sense of both the history and structure of the scandal but also, crucially, how the people and institutions embroiled in it have explained what on earth they've been up to. It's everything we've looked at so far – how certain qualities of a system behave, but also how these behaviours are captured and performed. So much of the marketing spiel around cars is centred on 'performance' – how a vehicle combines engine power with elegant handling; but what these men on camera are doing is also a performance, driven by narrative intent to own a small pebble of the blame but deny much of the rest.

We have come to the end of the book now, and it is time to bring all the pieces together to think about not what happens when a system functions but when it breaks. If they go down, large, long-lived distributed systems often cannot be rebuilt because of all the layered, nested dependencies contained within them. The cause of collapse gives a sense of these dependencies, whether technical or ideological.

In her manifesto *Glitch Feminism*, Legacy Russell writes of the glitch as ‘an error, a mistake, a failure to function . . . a part of machinic variety, an indicator of something having gone wrong’ – a refusal to what the system expects.[1] What do we see when things fall apart and the centre cannot hold?

One of the most common answers to the question ‘what happens when systems break?’ is that they become visible. This idea can be traced back to Susan Leigh Star’s article from 1999, ‘The Ethnographies of Infrastructure’, in which she writes: ‘The normally invisible quality of working infrastructure becomes visible when it breaks: the server is down, the bridge washes out, there is a power blackout. Even when there are back-up mechanisms or procedures, their existence further highlights the now-visible infrastructure.’[2]

Though this line of thought has been challenged, the idea of functioning infrastructures (and, by proxy, systems) as unseen has become doctrine for how systems are conceptualised as a hidden backdrop to the real world. But as we’ve seen, systems don’t need to stop functioning to overspill their boundaries and become present, if we know what we’re grasping for. As the anthropologist Brian Larkin advises, instead of assuming that systems are inherently invisible, it is far better to ask how and why we are asked to avert our gaze from their presence at certain junctures.[3]

In the sweltering basement, Oliver and I quickly realise that none of the answers given by these senior executives really deal with the complexity of the multinational Volkswagen Group, nor the intricacies of supply chains and material or manufacturing and regulation that go into automotive production; specifically, there’s no detail of the software that’s at the heart of it all. What once was just a car is now a cyber-physical entity, strung through with hundreds of thousands of lines of code. Instead, the finger is pointed again and again at one man, a ‘rogue engineer’ who is foregrounded as the single source of the largest and most expensive industrial scandal in recent history. If this is what our attention is drawn to, what are we averting our gaze from? What are we not meant to see?

Let’s start by thinking about what a car crash means.

‘To invent the sailing ship or the steamer is to invent the shipwreck. To invent the family automobile is to produce the pile-up on the highway. Every technology carries its own negativity, which is invented at the same

time as technical progress.'[4] This, from Paul Virilio, has become sacrament for thinking about how emerging technologies bring something new and fearful with them into the world. Our next step is to explore what these negativities are and, crucially, how they differ from each other.

We could look to systems theory for answers and end up with very technical descriptions of resilience mechanisms, feedback loops, the vulnerabilities of flow-dependent just-intime processes, and more. But by now, we should be asking for more than this. We should be asking: where are the power dynamics? What are the cultural meanings associated with these descriptions? How are they deployed, and who do they serve? Cars hold prime real estate in the public imagination and have done so for more than a century; but as any maritime art historian will tell you at length, ships got there first. Across the canon of the history of ideas, shipping and shipwreck metaphors endure to the point of cross-stitched mottos: Life is a perilous journey across uncertain waters! You are master of your fate and captain of your soul!

Like cars, ships can be seen as an expression of masculine control over nature and faith in technology – but they also carry the scent of naval strategy and imperial superiority. Most of all, ships go out to sea. Maritime art scholars distinguish between the 'dry' world of the liturgical ship, worshipped by nations, sailing serenely on the waves under male control; and the 'wet' world of the sea, an infernal space, fluid, active, uncontrollable, swarming with demons and monsters and capable of tearing fixed structures beam from beam.[5] So when the ship goes down, the shipwreck embodies a loss of masculine control over technologies and the tragedy and pathos of failure, but also the disruption of the hegemony of empires and the futility of greed.[6]

In artworks from the early nineteenth century depicting shipwrecks, neither individual people nor technical failure are positioned as responsible for what has happened. Instead, the wreck is a tragedy where the wet world takes over and the sublime is sparked. In J. M. W. Turner's *The Wreck of a Transport Ship* the sea is a mass of hostile animus, its waves reaching higher than the sightline of those wretches who are trapped on the wreckage torn apart by turbulent waters under darkening grey and orange skies; land is nowhere to be seen. When spectators on the shore are depicted, they are

lamenting, horrified by what is happening out at sea but utterly unable to help.

By the end of the nineteenth century, the horror of the shipwreck had been abated somewhat by modern safety inventions: navigational devices, steel ships, better charts, communications technology, and weather forecasting – nothing that reduced the power of the sea, but which allowed sturdier ships a safer passage and rescue from new humanitarian ventures. Artworks reflected this shift: spectators were now actively involved in rescue missions, and narratives around shipwrecks had shifted from the spectacle of despair into the spectacle of heroism.[7] Also, by the end of the nineteenth century, the first cars were on the road.

Like ships, cars are a transformative technology, enabling further and faster forms of movement, shifting political and economic structures as they move.[8] But symbolically, cars are a completely different beast. If ships stand for a shared confidence invested by nations over nature, cars are a dream of independence, freedom, and a sleek, shining, industrial future. Ships embody the power of the collective; captain, crew, cargo, and the culture that built them, and so the shipwreck is a mass event, a destruction of the faith invested in the construction of the ship. But cars gift that power to the individual, the driver, barrelling faster and faster down the roads towards a technological utopia shining on the horizon.

But perhaps most importantly for thinking about how things break, the shipwreck is ultimately caused by the sea itself and the devils (rocks, icebergs) that lurk within it. The car crash – that pile-up on the highway – is fundamentally different. Its seeds of destruction are contained in the prime objective of the car: the desire for speed.[9] Ships were depicted in oils by painters commissioned by kings and emperors to document their naval superiority, but it was speed itself that was captured through new technologies of photography. In both Eadweard Muybridge's pioneering stop-motion photography, and Étienne-Jules Marey's work, in which successive phases of movement were captured in a single frame, we see the foreshadowing of the later photographic techniques which were an intrinsic part of car crash testing.

In paint, artists of the Futurist movement conveyed the velocity of this new industrial age through multiple overlapping images. In *Dynamism of a Car* by Luigi Russolo, a car, fragmented and reassembled through dark grey

triangles, moves through a field of stacked red and yellow arrows which, right to left, become compressed to indicate extreme speed. Is this the car or is this the crash? Here, torn apart by velocity and surrounded by the licks of the arrows, it doesn't matter – they are the same thing. 'Come my friends!' writes Fillipo Tommaso Marinetti in the *Manifesto of Futurism*:

> Let us go! At last Mythology and the mystic cult of the ideal have been left behind. We are going to be present at the birth of the centaur and we shall soon see the first angels fly! We must break down the gates of life to test the bolts and the padlocks! Let us go![10]

The danger and destruction wrought by motive power is the point, tearing down the old world to bring in the new. 'We drove on, crushing beneath our burning wheels, like shirt collars under the iron, the watchdogs on the steps of the houses,' Marinetti writes, leaning into the violent elements of Futurism which he later expanded into his work within the Italian fascist movement. What we see play out over a series of movie franchises holds true a century earlier: that speed and annihilation are visceral pleasures, best experienced in the real but parts of which can be reconstructed and simulated for an audience. Decades before crash testing became an established scientific field, showmen in fairgrounds staged 'auto thrill shows', where actors smashed cars into flaming walls in head-on collisions or drove off high ramps to land on top of other vehicles, even driving over human 'Iron Men'.[11]

Truth be told, there's little in the way of visceral exhilaration from the Volkswagen government hearings; the only death-wish is to make the long hours of dry interrogation stop. Underneath it, though, there's a hum that runs through the constant invocations of a 'rogue engineer'. The whisperings of Mark Zuckerberg's call to 'move fast and break things' summons up a cleansing fire that burns away the old. To be clear, the industrial systems that Volkswagen and other automotive engineers have operated in are structurally separate from those of the Bay Area and Silicon Valley where this motto arose; and yet, this impulse to put software to new uses has become intrinsically associated with breaking shit and not worrying about the consequences. And at the core of the Volkswagen emissions scandal is software.

Even more traditional business school analyses of innovation carry an air of breathless excitement. Clayton Christiansen's classic work on disruptive innovation, *The Innovator's Dilemma*, is less well known than

Zuckerberg's poster motto (though it did have a cameo in the tech billionaire murder mystery film *Glass Onion: A Knives Out Mystery*) but it lays the intellectual groundwork for the later smash and burn ethos. Here, Christiansen argues that small businesses can fundamentally change the structure and behaviour of an industrial sector, if they act in the right way and move in the right time. They can *disrupt.* This builds on a much earlier idea developed by the economist Joseph Schumpeter, of creative destruction, which describes how the economic structures of entire industries could be revolutionised from within by entrepreneurs, destroying monopoly power and sustaining economic growth. Schumpeter saw entrepreneurs as 'wild spirits', reaping the 'perennial gale of creative destruction'; Christiansen was less passionate in his language, but 'disrupters' are spoken of approvingly; a punk framing of economic strategies that speeds past what is lost in the industrial shakeup – jobs, livelihoods, knowledge.[12] Breaking things is great so long as you can walk out of the crash unscathed.

At the industrial scale, the automotive industry has been shaken up by speed many times over, from machines that sped up production, to the introduction of software to control, first, engine function and then, everything else. As the design curator Brendan Cormier writes, the entire history of automotive design can be characterised by the individual desire to go fast and the collective desire to be safe.[13]

To understand how a vehicle breaks and the structural forces that have gone into breaking it, let's take a look at what a car is and where it came from. The Mercedes-Benz Museum sits on a small hill on the outskirts of Stuttgart. From the outside, it looks like what might happen if automotive engineers had accidentally been contracted to design a building: an angled slab of layers of matte silver metal and smoked glass, resting on angled struts. Part car, all edifice, it is the queen bee to the thousands of vehicles built in the city. Stuttgart is a factory town where the automobile industry is monarch. Mercedes-Benz, Porsche, and Audi all have plants here. It feels like what children imagine adult life is like: a clean town surrounded by mountains where everyone has extremely fancy cars and, if you head out of town, the wide roads will take you on to the Autobahn where you can drive as *fast as you like.*

I came to Stuttgart to explore how cars break; that is, how automotive companies think that cars break and how that influences the ways in which

cars are designed. As Gijs Mom writes, the history of the automobile is more about cultural triumph than technological progress: cars today have developed out of everyday cultures of how people feel about cars, and are intractably bound up with history, culture, industrial dynamics, and regulations.[14]

What we may think of as ‘car culture’ and its associations with progress and individual freedom has a particular American bent.[15] Things are different here in the German state of Baden-Württemberg. Volkswagen is not here; its main manufacturing works are more than 250 miles up the Autobahn in Wolfsburg, but Porsche is in Stuttgart and Volkswagen own Porsche. Bosch are headquartered in Stuttgart – the company doesn’t make cars, but it does make parts and that fact will become very important to us shortly. Mercedez-Benz has its head office here too; formerly Daimler-Benz, it was founded by three men who had invented different versions of the one thing that makes a car, today, a car – the combustion engine.

The timeline in the museum runs top to bottom. As you exit the elevator on the highest level, you are greeted by a life-size model of a white horse, a reminder of the original source of autonomous motive power. Then, in the first gallery, those original high-speed internal combustion engines are on display. There are the devices invented by Gottlieb Daimler and Wilhelm Maybach – the first preliminary engine which was patented in 1883, followed by the ‘Grandfather Clock’ in 1885, so named because it looked like a swinging pendulum. Both were small and light enough to fit inside a vehicle and strong enough to power it. The question was, what type of vehicle would it be?

The gallery has a range of machines flexing and convulsing to find their form as the engineers attempted to find something that could be wrapped around their new invention. Daimler and Maybach tried the ‘Riding Car’ – really a steampunk-flavoured motorbike with a quilted saddle and wheels resembling cogs. They inserted the engine into a dirigible that made its trial flights out of Tempelhofer Feld in Berlin; they put it into motorised trucks used by breweries to transport their beer. They even considered whether horses could stay in the picture with the ‘Feuerspritze’, a fire-fighting machine towed by the animals, but carrying a water pump powered by a two-cylinder engine.

And then, the Benz Victoria was developed in 1893. Though its quilted leather seating and curved roof still bear the genetic inheritance of the horse-drawn carriage, this four-wheeled vehicle laid down the structure of what we can now think of as a car. Unlike previous iterations, its two front wheels steered independently from the rear, letting it better manage curves on the road, and the engine power allowed it to reach awesome speeds of up to eleven miles per hour.[16] Later innovations tweaked and primped the car, replacing the flames in the front headlamps to battery-powered bulbs, but the concept remained, roughly, stable from here on out and pulled into the slip-stream of mass production. Any attempts to repurpose the machine was now in the hands of its users, if they had the know-how to do so: in America, farming communities mechanically dismantled their vehicles to repurpose them into tractors and ploughs, or simply pulled out the most valuable part of the beast – the engine – and used it to power their laundry machines.[17]

This feels like the start of a success story for the nascent German automotive industry, and certainly the museum would like to spin it that way – a clear line from those early proto-cars on display at the top of the museum and the flash boy motorcars on the lower levels, down to the luxury machines driving through the city. But cars just did not take off in Germany. The engineering was fine – great, even! – and automakers did well in selling their parts overseas, and yet, the locals were not buying. By 1925 when the American automotive industry was taking off, Germany was lagging – out on the German roads, there were still slightly more horse-drawn carriages than motorised vehicles.[18] In 1929, analysts from General Motors ascertained that the German market was eighteen years behind its US counterparts; by 1932, Germany was one of the least motorised industrial nations. Rather than lobbying to build motorways in line with their US counterparts, a collective of German manufacturers – the Reischversband der Automobilindustrie – were worried that their vehicles wouldn't be able to withstand the sustained stress of fast overland driving.

It's worth taking a moment here to think about how these differences shaped attitudes towards automotive safety. In America, the automobile was king and could do no wrong. Any problems around production or maintenance of new cars were typically suspected to be the result of human failings rather than mechanical error.[19] Accidents – and there were many –

were blamed on reckless drivers belting down the roads at high speed. Early attempts to understand road accidents were based around forensic examination of the crash site after the accident had occurred. General Motors opened their first proving ground in 1924 in Milford, MI, as a place to test and document the circumstances in which drivers found themselves in on American roads.[20] The tests themselves were designed around data from insurance forms that described the conditions which had led to the accidents, but the subsequent new designs only involved components that supported crash avoidance, not any interrogation of the structure of the vehicle itself.

In Germany, the Autobahn proposal was revived – not to meet customer need, but as a political propaganda project by the Nazi Party. As the historian Thomas Zeller explains, from a military standpoint Germany really had no need for motor-ways, being a country both with lagging rates of motorisation and extensive railways. Nazi transportation policy, however, devised a plan for 'gigantic road networks' with a corresponding affordable car for the masses – the Volkswagen. Through automobiles and Autobahns, the party lashed together a promise of modernity and economic recovery, as the unprecedented purpose, design, and scale of the Autobahn mirrored the unprecedented nature of the regime.[21] The accelerating thrust of motive power was intentionally coupled to a violent political movement. The Autobahn was not only another vanity mega-infrastructure project for people to goggle at, but one in which they could experience the speed of change wrought by the government. As Zeller points out, there was also another unpleasant resonance between the American and German car regimes, as Adolf Hitler was 'fascinated in equal measures by Henry Ford's mass production of cars in Detroit and by his anti-Semitism'.[22]

The mass motorisation project was a failure. As the Second World War progressed, the Volkswagen plant shifted production to churn out military vehicles; many other automotive factories were damaged or destroyed by explosions. The Autobahn never became its whole self – parts were bombed, parts were paved over to form airstrips, and construction ground to a halt in 1943 as labour and materials were needed elsewhere. But, in the aftermath of war, that initial infrastructure was still there. In East Germany, there was little progress. Much of the car factory machinery was sent back to the Soviet Union as war reparations and then, under control of the GDR, the Autobahns continued to crumble. In West Germany however, things

were on the move. Under the Marshall Plan and through shifting economic sanctions, car manufacturers began to open up shop and rebuild their industry, and German creditors were incentivised to import German goods. Mercedes-Benz began manufacturing again in 1946, starting with the 170 Series that had been designed before the war.

Where does this leave us in terms of thinking about how cars break? Halfway down the museum – we are now in the 1950s – are a collection of objects that resemble children's toys which indicate the car safety culture at play. By now, German automotive engineers had rebuilt their testing facilities and begun visiting American universities and manufacturers to learn from them. Still, the German focus continued to be on the construction of the car, rather than driver behaviour. Was it stable enough to cope with motor-way driving? Could engineers remedy the 'unwelcome effects of oscillating vibrations', as some of the first safety experiments asked?

In a glass case are the first of these strange toys: large wooden balls, five kilograms each. Under test conditions, springs launched the balls inside a car to simulate a head cracking against them if the vehicle came to a sudden stop. Based on these exercises, safety features were incorporated into car design: windscreens made from laminated glass that held together when shattered and padded instrument panels to soften impact. Inasmuch as the driver was considered, it was as the potential buyer for an expensive consumer good, not a boy racer. While safety tests indicated that the decorative wooden trim might splinter during a crash, customers felt that this decoration was an important feature in a luxury vehicle. Thus, engineers developed composite wood materials with aluminium inserts that held its integrity in a crash. These adaptations joined a batch of passive safety features developed by engineers at other companies, including seatbelts and airbags: entities that only became active during an accident to reduce injury, requiring no effort from driver or passenger.

The second strange item is a peculiar metal object on wheels: a cylinder stamped in royal blue check sitting inside a bright red cage, with a vent on the back and a warning sign reading *ABSCHÜSSE* ('launches'*)*. This is the hot water rocket, and it works like this. The device is mounted on to the rear of a test car, and filled part-way with water which is then heated: when the temperature hits 260°C, steam pushes the valve open and the thrust

accelerates the car to speeds over 100 kilometres per hour. The car is then ploughed headfirst, and at tremendous speed, into a wall.

The hot water rocket marked a moment in German car safety testing which allowed vehicles to move freely, absent a driver. At the Mercedes-Benz proving ground on the outskirts of Stuttgart, engineers were setting up their own version of the auto-thrill show, with cars spinning off inclined planes and crashing into things; not for entertainment but to recreate, document, and analyse the crash in the whole: a complete analysis of collision dynamics in a contained space. To gather the most accurate information, the collision needed to be simulated as comprehensively and realistically as possible. But, as the wooden ball tests showed, a realistic car crash could physically devastate the human operator required to drive the car.

Now, engineers could stage their crashes as effectively as any showman, controlling speed, the angle of approach and site of impact. Cars ploughed into barriers to simulate the head-on collision with a building or vehicle. They were propelled up corkscrew ramps and swivelled on their horizontal axis to land on their roofs as though they had flipped a kerb or spun though the momentum of a particularly vicious crash. Instead of spectacle, the crash was a site of scientific enquiry. High-speed film and acceleration sensors were introduced by carmakers to capture the moment of impact, and then, the moments after it. In the crash, structural failure and unconfined movement transformed the fixed form of the vehicle into something else entirely, where glass shattered and steel rippled. And thus, the rational techno-scientific ritual of the crash test was founded. As the media scholar Greg Siegel writes, ‘That which enhanced the excitement of thrill-seeking spectators – namely, the collision’s material and spatiotemporal contingencies, its accidentalities – undermined the aims of truth-seeking researchers.’[23] In the artificial environment of the staged crash, all potential for human error – the very thing that so often led to the accident itself – would be minimised.

Breakage is an event: it is a situation, not a subject. To break something is to learn something about it, in what the social scientist Steven J. Jackson describes as the world-revealing properties of breakdown.[24] Crash simulations provided answers about what happened in the moment of collision, but also raised new questions, one of which was: as a vehicle rapidly decelerated into a crash, where did its kinetic energy go?

Earlier forensic examination of aeroplane crash sites by the American engineer Hugh De Haven had determined that the human body was capable of withstanding the tremendous forces caused by impact providing that they were protected by a crashworthy structure around them.[25] In the United States, this observation shifted the nature of automobile safety away from preventing accidents by reforming the reckless driver, bringing it more in line with the German strategy of reducing injuries and fatalities by re-imagining the automobile itself, and ushering in a new job title: the safety engineer, whose dedicated role was to research vehicle impacts.

One of the first safety engineers was Béla Barényi, hired by Daimler-Benz in 1939, and who worked on the energy problem. As a car crashes, the kinetic energy released by its sharp deceleration transfers into the body of a vehicle, collapsing it (think of what happens if you drop an egg onto the floor – the shell will shatter). Building on de Haven's research, the prevailing view at the time was that a car body with maximum rigidity best served passenger safety. However, subsequent crash test research showed that, while rigid structures withstood impact, the energy of the collision would then be transmitted through them and into the occupants, who would be thrown around the structure as clothes are flung around a rotating washing machine drum.

If the car body were built from softer, more malleable materials then the energy of the crash might be absorbed into the frame as it crushed – but this would then also crush the passengers. What to do? Barényi's innovation was to split the carriage into three parts. At front and back were the new 'crumple zones' which would collapse through controlled deformation on impact, increasing the time that the vehicle took to come to a stop and reducing the magnitude of forces felt by the passengers. In the middle of the car was a rigid compartment – the safety cage – which protected passengers.

The invention of the crumple zone formed part of a critical turn in safety-testing, suggesting that because drivers could not help but be involved in accidents, carmakers were implicated in motor fatality rates and had a responsibility to design and manufacture crashworthy cars.[26] As a corollary to this, carmakers realised that they could sell themselves through their dedication to safety – on visiting the Ford crash testing facility in 1955, Mercedes-Benz engineers were surprised to find their US counterparts already using accident research in their marketing. This shift

went hand-in-hand with increased regulation around automotive design. From field tests to laboratory conditions, the spectacle of the crumple zone crumpling became the crash test's ritual object.

The closed circular logic of the techno-scientific ritual is only as successful as its initial starting conditions. While the crumple zone was effective in channelling energy away from passengers, its design was still predicated around what was assumed to be the most common type of car accident – the head-on collision, in which cars would drive straight into a barrier or another vehicle, colliding bonnet-to-bonnet. But accident reports from around Stuttgart indicated something else was happening.

Rather than crashing head-to-head, cars driving towards each other in opposite directions were more likely to collide on their edges, clipping shoulder to shoulder. This is the off-set collision, where a quarter or less of the dashboard collides with something else, and it is lethal. Only a small part of the crumple zone is able to absorb its impact. Instead, the car is sent into a spin, ricocheting passengers into the pillars, doors and windows. Once the facts of this type of crash were known and had been brought into the lab, it could be reproduced and analysed. While those earlier tests with wooden balls attempted to simulate cranial collisions, the speed and rotation of the offset crash was more likely to result in internal organ injury.

Following on from these types of discoveries, Daimler-Benz expanded the testing framework into 'systemic accident research' – distinct from reassigning blame back to the individual driver, this framework asked not only what happened in the instance of the crash, but also what was happening in the wider social system in which the vehicle operated. Nevertheless, the shift from 'road to lab to math' continued, relocating the understanding of vehicle dynamics to controlled laboratory experiments and maths-based simulation models.[27]

The museum is a controlled environment, of course; every vehicle there is fixed in place, on show, ready to be walked around and examined and admired. It is a surprise to walk out into the warmth of the summer afternoon and see cars doing the thing they're engineered to – driving. Here on the intersection of roads by the river Neckar everyone seems to be moving at a gentle pace and I remind myself that the speed limits in German towns and cities is a paltry fifty kilometres per hour, monitored by traffic cameras.

Yet two motorways flow into the city nearby. Stuttgart is located in what was then the Federal Republic of West Germany where, after the war, the damaged stretches of the motorways were repaired through infrastructure investment. In 1952 the government of West Germany abolished speed limits on the Autobahn. Today, the Autobahn itself is synonymous with freedom from limitations and control.[28] EU attempts to enforce country-wide speed limits to fight global warming have been met with counter protests and the slogan 'Freie Fahrt fur freie Burger' (free driving for free citizens). Speed tourists come to Germany with an idea of enveloping themselves in what the sociologist John Tomlinson calls 'unruly speed', a thrilling sensuous aesthetic experience which ruptures and – yes – disrupts the mundanity of everyday life.[29]

But there's a difference between the individual dream of speeding unencumbered and the actual real-world collective experience of driving the Autobahn which can be, my friends in Germany tell me, truly terrifying. For the less confident driver, crossing the border over from Switzerland can leave you with your heart in your mouth as every vehicle suddenly ramps up their pace in the lanes around you. If you don't increase your speed, then you become the danger on the road.

For the experienced Autobahn motorist, however, the experience is coloured by a different approach to speed, based on rationality and efficiency – 'machine speed'.[30] Though the driver will undeniably derive some unruly visceral thrill from belting down the roads, this feeling will be grounded in the knowledge that they are driving an expensive piece of advanced engineering which has been created to protect the passenger. No matter your speed you'll always be driving safely because your car is so expertly engineered with, say, incredibly long crumple zones. And, as my friends explained: 'Why buy a car that goes up to 120 miles per hour if you're not going to drive at that speed?'

Back in London, Oliver and I have begun sifting through the marketing videos put out by Bosch, the engineering company that manufactures the EDC-17 Engine Control Unit (ECU) at the heart of the emissions scandal. We have found that the apology videos only get us so far: while, on the surface, these men appear to be showing deep regret for the largest industrial scandal in recent history, their sad faces and servile tones don't line up with what's actually being said, with little to no acknowledgement

of Volkswagen's deception or admission of wrongdoing. Instead, the public apologies consist of executives like Martin Winterkorn arguing that it was unfair to blame six hundred thousand hardworking individuals for the mistakes of a few people.[31] The company is unblemished and still trustworthy, these men say, though this rallying call to restore public trust is at odds with the sweat on their foreheads under the bright lights.

So, we turn to the videos produced by Bosch in the years leading up to the scandal; the time period in which hundreds of thousands of Volkswagen vehicles were already pumping out illegal amount of deadly emissions but had not yet been detected. These videos show a different type of performance: one which also builds a case for faith in technocratic institutions and the very sleek machines and people within them, but from the perspective of the hero, not the criminal.

One internal promo film takes us on a tour of a Bosch plant, where gorgeous people walk along gleaming hallways of advanced technology, and trim engineers tend to rows of gleaming 3D printers while tiny convoy vehicles zip up and down white-walled corridors. Everything is very clean. The film is scored with a peppy electro soundtrack which earworms its way into our skulls for the rest of the summer. Underpinning this cavalcade of technology theatre is the emphasis that what's on display here is both reliable and desirable because it's built using German engineering. *Car* and *German engineering* rotate around each other as metonyms: even if what's on offer isn't actually a car, it's made by a German company that makes parts of vehicles and that's close enough. A Bosch advert from 2012 opens with what appears to be the silhouette of a car shrouded in a white cloth, which is then pulled away to reveal that the 'car' is actually a collection of domestic appliances. The tagline: 'German engineering you park in your kitchen!' Volkswagen itself has always been explicit about its relationship in this metonym, with a 2014 slogan stating, 'Everyone knows that the best cars in the world come from Germany – isn't it time for German engineering?'

And technically, yes, 2014 was the time for German engineering because that was the year that the emissions scandal really kicked off. Here, it began when the International Council on Clean Transportation contacted the Centre for Alternative Fuels, Engines and Emissions at West Virginia University with a request. Could the Centre's research scientists test the

emissions from three diesel vehicles under more realistic conditions than were possible in the lab?[32]

To be sold in America, cars have to pass the Environmental Protection Agency (EPA) standards for emissions, which had joined the battery of other forms of vehicle safety tests to be performed under laboratory conditions.

One of the groups of substances tested for in emissions testing are nitrogen oxides (NO*x*). When the NO*x* produced during combustion are combined with volatile organic compounds, they form ground level ozone, a trace gas that can cause severe respiratory problems. In these tests, cars were tethered on to a chassis dynamometer that held the body in place while allowing the wheels to rotate freely. The car then 'drove' on an industrial scale-treadmill at a precisely defined speed profile while the gases being pumped out of the exhaust pipe were gathered, and later analysed. Similar to the hot water rocket many decades earlier, the emissions test attempted to mimic real-world driving conditions in a controlled, monitored environment. But something had gone wrong. A small group of cars seemed to be giving different readings depending on whether they were being tested in the lab or out on the road. Either the laboratory testing equipment was faulty or the environment that the vehicles were in was somehow changing their behaviour.

Scientists fitted the suspect cars with portable emissions measurement tools to gather a continuous range of data and, with driver onboard, sent them off to drive around different types of actual roads. What came back confirmed initial suspicions: depending on the roads and driving conditions, the Volkswagen vehicles were releasing far greater levels of NO*x* than those permitted by the EPA. The VW Jetta emissions were up to thirty-five times higher, and the VW Passat up to twenty times higher.

My first thought on hearing about these tests was that these were the latter-day equivalent of the discovery of the offset crash in Stuttgart, where examination of crash sites revealed something unanticipated about real-world driving conditions and which could then be fed back into the controlled boundaries of the laboratory. But this was an unnatural inversion where the known experimental parameters were then knitted back into the machine to allow it to behave differently depending on its environment. The findings were passed over to the EPA, which promptly launched an investigation. The testing centre was, broadly, not at fault. Instead, it was

the cars themselves which were being gamed. Running through the guts of every ECU in every duplicitous vehicle was a piece of software that recognised whether or not the car was being tested or not. If it detected that the car was ‘driving’ under test conditions, the software nudged the ECU to shift the amount of NO*x* released to meet the approved levels. This software acted as what the EPA called a ‘defeat device’, and it had been inserted into a dozen vehicle models, scaling up to an estimated 11 million cars worldwide.[33]

From here, things fell apart pretty swiftly, with the EPA issuing a notice of violation to Volkswagen AG, which admitted the use of the software. The following day, on 23 September 2015, Martin Winterkorn, chairman of the board of management of Volkswagen AG resigned; five days later, German authorities opened a fraud investigation on him. In October, German authorities authorised a raid on the company headquarters. Mid-month, Michael Horn (CEO of the US division) testified to Congress in Washington; six months later he formally resigned, in March 2016. It took another two years before Winterkorn was formally charged with fraud and violation of the Clean Air Act by US authorities in 2018. Criminal charges were brought against the company and a $2.8 billion fine levied by a federal judge.[34]

Through it all, the case attracted vast media attention, centring several easily digestible tropes. There was the corporate behemoth and its men in grey suits, putting profit over lives, and the satisfaction of seeing it collapse; in addition to the criminal charges, Volkswagen stock lost 40 percent of its value in two weeks. And there was the old sci-fi narrative of an advanced technology that had been repurposed into a different kind of killing machine, together with the hoariest trope of all: the mad scientist gone deranged with power, the ‘rogue’ engineer.

Brought together, these clichés flattened out the nuances at the heart of the story of who, how, and why. Describing the malicious firmware (a type of software which can control hardware) as a ‘defeat device’ effectively black-boxed what, technically, had happened. Little of the reporting got much further than describing it as a piece of software which suppressed emissions when a vehicle was put under test conditions. I might as well have tried to glean information about specifics of the firmware from Bosch’s own marketing videos for ECUs, which digitally rendered the engine management system as a literal black box strewn with black cables,

with ‘data’ represented as neon blue zeroes and ones flowing up and down the apparatus.

However: the scalable quality of software that allowed the defeat device to be easily and vastly multiplied into millions of vehicles did give greater credence to the argument made by VW executives that a single person was at the root of the scandal. In the midst of the executive hearings, the first individual guilty plea was submitted by James Liang, a sixty-two-year-old engineer who had worked in the VW diesel development department from 1983 to 2008. We found no recordings of Liang publicly apologising in the direct-to-camera manner as his superiors, only the head-down walk of shame as he and his attorney were chased by camera crews on the walk up to the courthouse.

Here, then, was the *why* of it all: according to his plea agreement, Liang and his team had begun building their new diesel engine in 2006 and, when it became apparent that it could not meet consumer expectations around performance for compliance with environmental standards, they began exploring ways of circumventing the testing. Decades of research demonstrating the environmental damage of diesel vehicles does not override the century-long desire of car owners wanting to drive fast.

We could get into the weeds here about complicity. Whether, as the executives claimed, Liang and his team really were acting alone, hiding their illicit activities from the rest of the company; or, as government lawyers alleged, that senior staff had known about the device all along, even rewarding those involved in the project.[35] But I think that line of questioning takes us away from the more interesting question of why, in an extraordinarily complex system of supply chains, manufacturing and engineering, Volkswagen executives were so determined to control and contain the cause of the wrongdoing by assigning the shadowy figure of the rogue engineer as the locus of guilt. And yes, the technologies through which these accidents operate are complicated and control is scattered across many different agents through time and space; and, as we have seen, the executives ended up being jailed too, so why does it matter so much to contain the blame in a single, lowlier man?

Though the largest and most expensive in recent history, the emissions scandal has its predecessors in which engineers and technical operators were also scapegoats. In her work exploring how blame gets attributed in large-scale industrial accidents, and specifically autonomous car crashes,

Madeleine Claire Elish identified the phenomenon of the ‘moral crumple zone’, in which responsibility gets misattributed to a person who has limited control. If the system works as planned, success gets attributed to the efficacy of technology; if it fails, human operators are blamed. This, Elish acknowledges, has some equitable grounding: non-human entities cannot yet be held responsible to society in ways that contribute to justice and the greater public good.[36]

This still leaves the question of why technical operators take the fall. In the aftermath of autonomous car accidents, it was the human back-up drivers who absorbed the shock of responsibility. People are involved at every stage of the process of manifesting a Tesla or a Volkswagen out of the ether and on to the road; but, when ‘human error’ is invoked, it refers to operator error rather than that of designers or systems architects. This resonates with those first few decades of car safety experimentation where reckless drivers, rather than the car itself, were held responsible for crashes. But James Liang was an engineer; he worked to calibrate and refine the defeat device, moving to the US in 2008 to help with testing and, as his plea bargain states, doing so with full knowledge that vehicles with the device were being marked as environmentally ‘clean diesel’.[37]

And yet: I think the framing of the moral crumple zone applies equally well to Liang, and to any other ‘rogue engineers’ out there. Remember, the crumple zone exists to protect passengers who are held in the rigid safety cage; it achieves this purpose by absorbing energy and destroying itself. So, what does the moral crumple zone protect? Not senior management, as we’ve seen from the downfall of the Volkswagen’s C-suite of men. What I think it protects is the psychic integrity of a technological system throughout space and time.

Different pieces of the system might take a hit, but the idea of the functional whole, of cars as seamless cyber-physical entities which were always destined to exist, survives. Engineers and vice-presidents might be jailed, more stringent emissions tests might be introduced, but the system will abide. As we’ve seen throughout this book, the sheer complexity of these types of systems means that they defy simple exposition. When a straightforward narrative is applied, viz. ‘A bad man did it and ran away’, we now understand that this story does not explain or simplify a difficult knottiness, but instead distracts attention as an act of self-preservation.

If this is the ‘why’ of the emissions scandal, is there anything left for the ‘how’ to tell us? Can we even ascertain what the ‘how’ is? At first glance, this question seems to slam us up against the sealed industrial closures of automotive manufacturing and its closed vaults of proprietary information. Though the parameters of emissions testing are public, allowing them to be performed by third parties and gamed by crooks, the black-boxed nature of the software involved make it nearly impossible to examine. To date, regulators have had to rely on huge fines to discourage cheating, bringing to mind the aphorism that if the penalty for transgressions are financial, laws will apply only to the poor.

But there is a way in, courtesy of a group of German and American engineering scholars, who tell us how the defeat device worked and, more crucially, how they uncovered this information, in their perfectly titled research paper: ‘How They Did It’.[38]

Despite being credentialed academics from Ruhr-Universität Bochum and University of California: San Diego, the researchers were not given any privileged access to proprietary firmware. Instead, they took a sideways approach to their forensic investigation, and asked: beyond manufacturers, who else might want to modify car software? The answer, of course, is car modders: colloquially known as ‘car tuners’, these are the folks who mould and tweak their vehicles to make them into something other than their manufacturers intended.

Car tuners tend to adapt vehicle engines to improve performance, allowing folks to drive faster and smarter. Repurposing a cyber-physical entity that looks like a car is more challenging but not impossible if you have the right elements. What you’ll need are images of the firmware, official versions of which can be found in car repair shops. Then you’ll need function sheets (*Funktionsrahmen)* that document the functional behaviour of a particular piece of ECU firmware through a block diagram. Finally, you’ll need the A2L and OLS-format files, which describe which elements of the firmware image must be modified. These latter two are not meant to be available to the general public and yet often find their way into online car tuner communities. By digging through car tuner websites, the researchers assembled a full complement of images, function sheets, and files, which through adversarial triangulation (that is, intentionally looking for harmful behaviour) and reverse engineering, they identified the defeat device – what it was, and how it worked.

Or rather, how *they* worked. The defeat device turned out to be a continually evolving family of devices that were all organised around a single monitoring event that calculated the state of the car's coolant, fuel, and oil temperatures, together with its atmospheric pressure. If all were in a specific range *and* the engine was then started, the flip was made and the device kicked in. And that was how they did it.

Coming out of the project, it was difficult for Oliver and me to feel cheerful about any part of what we had learned. Despite the scandal, Volkswagen had emerged relatively unscathed, with sales actually increasing in 2016; unlike its competitors producing electric vehicles, Volkswagen had never sold itself hard on any environmental credentials. In a particularly dispiriting turn of events, it transpired that consumers were more upset about the effect of the defeat device on their car's performance and the inconvenience of recall than they were about the emission of poisonous gases into the environment.[39] Even the success of the researchers who tracked down the defeat device was undercut by their own warnings that as software control becomes a pervasive feature of complex systems, regulators will be faced with certifying software whose manufacturers both have an immense financial incentive to cheat and the capacity to do so.

Black-boxed software may exist undetected for an extremely long time: instead of the ship crashing into the rocks or a car exploding on a motorway, imagine a machine simply going about its business, behaving efficiently and with silent malice for years and years. In a perverse way, the Volkswagen emissions scandal was blessed by having occurred through the medium of cars – consumer objects, owned by millions, and hacked, modded, and boshed since the very start of their existence. The next scaled software disaster may not be so easily accessible.

But we can also think about what kind of world was revealed in the breakdown and, again, what was not revealed; what we were not intended to look at. Breakages are a suspension in time that expose power structures. Throughout the scandal, the pleasure of breakage was gifted to those in control of the system of automotive manufacturing. There's a chorus of voices arguing that cars are anachronistic, no longer seen as an item of individual selfish consumption but, through sharing platforms, part of a large community – and yet, they still exist.[40]

To end where we began: systems are difficult to comprehend. It is hard to parse a complex nested web of structure and behaviour which stretches and warps through time. It is far easier to draw the eye to a single node of operation such as a rogue engineer or even a reprobate CEO – but doing so intentionally detracts attention from the system itself, permitting its survival. In the same way, it's necessary to look at the story that's being sold alongside the system and its behaviours to think about where this narrative comes from, what it is doing and who it serves. Cars are only individualistic joy machines if you don't consider the wider impact of their presence in the world; tearing shit down or blowing shit up is incredibly exciting and an exhilarating way of freeing oneself from the aggregate weight of complex systems, but only if you're not hurt by the consequences of doing so.

And yet – sitting with the breakage is necessary. Harnessing all of this knowledge of how the system works, how it *feels*, where the stories about it have come from, how it breaks, are necessary, to mend and repair and maintain if we need to; but also to hack it and tear it down; to refuse its power, if we want to.

Afterword / Ultra

In the final stages of editing this book – tracking down references, addressing editorial comments, making sure the narrative fitted together – I took myself off to see a film about railway infrastructure in the Soviet Union, as a little treat; a break from thinking about systems. Of course, it was not. In Tekla Aslanishvili's documentary *A State in a State*, everything we've been looking at in the preceding pages is right up there on the screen. Scale, matter, time, norms, breakage: the film has it all, showing how railway bridges behave differently when they're scaled up; how, through its scale, the railway created new projections of power, and shaped time; and, following the collapse of the Soviet Union, how it came to materialise the fragile political borders that emerged. Shot at the human scale – no god's eye view overhead drone shots here – Aslanishvili emphasises the experience of the workers over any grand exceptionalist narrativising about the technology itself.

But there's also a happier ending, of sorts, than the binfire of the Volkswagen emissions scandal. Together, the railway workers across Ukraine, Georgia, and Azerbaijan built networks of solidarity with each other; and then, even better, engaged in forms of industrial sabotage to push back against the violence of the Soviet system. As the documentary shows, the reason why political consciousness was raised is that railway infrastructure is a material system which affects people; not an abstract thing, but something which the workers labour on, together. The Soviet railways were a system of their own, with structure and behaviour; and, like the other systems we've seen here, capable of reproducing and enforcing power structures, bearing down hardest on those who are the most disenfranchised. But through mutual support, the workers were able to build

their own mode of resistance, challenging the authority and control of the system they worked and lived in.

Ultra: to go beyond; to transcend. As Valerie Olson has highlighted, many feminist, postcolonial and critical race scholars and activists have argued against the imposition of systemic forms which continue to benefit particular groups in a global context.[1] And still, we live in these large-scale technological systems that – through capitalism, financialisation, global supply chains; through kyriarchy – flex and bend to serve the most powerful. These are still both the cause and effect of wicked problems and, as we have seen, there is no One Neat Trick to solve them.

What I hope we have here, then, is a way to cut through – to go beyond, to transcend! – the stories that are told around complex systems: of their inevitability, and of their impossibility to parse, or their capacity to be fully mapped and controlled. Instead, by coming at them through the human scale, there are ways to tease apart the totalising and simplifying concept of 'system'. By approaching them with all of the meanings and affordances and scraps which make up human culture, we can see the ways in which they poke out through the world with all of their strange textures and ludic weirdness. By swapping out metaphors for metonyms, we can unbundle the cultural associations that stick to these systems, see where they link and twist together, and understand how their power and logics accrete and amplify each other.

Systems happen all at once and everything happens so much. Scale, time, matter, and deviance are a few points to feel out but there are so many more; and, as our railway workers show us, there are many ways to feel out the soft underbelly in these structures, through which they might be challenged, sabotaged, and maybe even, eventually, dismantled. As the Hacking/Hustling sex work collective reminds us: any system can be hacked; any system can be hustled.

This then, I hope, is the real systems engagement: not a literacy which is too similar to the forms of mapping which a systems approach encourages, nor a rubric which draws on a mode of analysis that carries the same authoritative sheen that characterises so much of what systems already embody. Instead, I hope for a sensibility in approaching systemic forms: embodied, visceral, critical; sometimes still, sometimes moving; sometimes furious, always curious; and which, together, can help us live in this complex world.

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At the end: it was only in the absolutely final, final, final_ FINAL2.lastversion stage of preparing the manuscript that I realised I hadn't directly cited Sara Ahmed's work on queer phenomenology. This felt like a strange oversight, since, truly, the entire sensibility behind *Systems Ultra* is coloured by Ahmed's approach: how to challenge what we assume to be 'normal' in what we experience in everyday life, how to approach it, and how it might be otherwise. So, with gratitude, I acknowledge the pervasiveness, the structural presence, of her enormous influence here.

At the beginning: the starting point for 'Systems! What do they want???' began with two projects: *Situated Systems*, with Ingrid Burrington, Sherri Wasserman, and Deb Chachra, and *Supra Systems Studio* (*SSS*), collectively co-founded by me, Tobias Revell, and Eva Verhoeven, at London College of Communication (LCC), University of the Arts London (UAL). In particular, a huge amount of the initial digging into systems came from developing the *SSS* exhibition 'Everything Happens So Much', and the associated publication. Enormous thanks to my colleagues and collaborators who were involved in this show: Rosie Allen, Ben Branagan, David Benqué, Tomasso Cesaro, John Fass, Gareth Foote, Alistair McClymont, Paul Bailey, Joel Karamath, Oliver Smith, Wesley Goatley, Marion Lagedamont, Jodie Newsum, Eleni Xynogala, Michael Sedbon, and Luisa Charles; to Shannon Mattern, Molly Wright Steenson, Sarah Hendren, and Natalie Kane for their written brilliance; and to Nicky Ryan for supporting this work.

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